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# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

DETERMINISTIC AGGREGATED MODEL OF STAR  
ON THE APPLE COMPUTER (DAMSTAC)

by

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and

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March 1982

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T204516



REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Deterministic Aggregated Model of STAR on the Apple Computer (DAMSTAC)		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis March 1982
7. AUTHOR(s) Charles J. McKenzie III Thomas Joseph Pawlowski III		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE March 1982
		13. NUMBER OF PAGES 178
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Army            Apple II Computer STAR            Lanchester-Type Aggregated Combat Model		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This thesis investigates the estimation of Lanchester attrition-rate coefficients in a deterministic aggregated combat model. Numerical values for the attrition-rate coefficients in the Lanchester-type model are taken to be the same as those for a corresponding continuous-time Markov-chain model and maximum likelihood estimators are developed for these Markov-chain coefficients. A discussion of the historical background of Lanchester's equations precedes the theoretical		



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Deterministic Aggregated Model of STAR on the  
Apple Computer (DAMSTAC)

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Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the  
NAVAL POSTGRADUATE SCHOOL  
March, 1982

---





## ABSTRACT

This thesis investigates the estimation of Lanchester attrition-rate coefficients in a deterministic aggregated combat model. Numerical values for the attrition-rate coefficients in the Lanchester-type model are taken to be the same as those for a corresponding continuous-time Markov-chain model, and maximum likelihood estimators are developed for these Markov-chain coefficients. A discussion of the historical background of Lanchester's equations precedes the theoretical development of components of the attrition rate equations. Using the functional forms and procedures developed by Gordon M. Clark in his doctoral thesis, a simple computer simulation program is developed for a short duration battle consisting of homogeneous forces. Recommendations are made to modify this program to model heterogeneous forces in a similar battle. A discussion of the theoretical background supports these recommendations.



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## I. INTRODUCTION

The purpose of this thesis is to investigate methods for estimating Lanchester attrition-rate coefficients, used in a deterministic aggregated combat model, from data generated by the detailed, high resolution Monte Carlo combat simulation model called STAR (Simulation of Tactical Alternative Responses). An additional purpose is to construct a simple Lanchester-type combat model capable of using the estimated attrition rate coefficients to predict the outcome of STAR simulations.

STAR is a model which has been developed primarily by U.S. Army students attending the Naval Postgraduate School. It has recently gained acceptance in the Army Community as a viable combat model, useful for studies such as the United States Army Mortar Study to be conducted in 1982. The current version of STAR is written in SIMSCRIPT and requires about 2 megabytes of core storage. The run time for one replication of STAR involving a company size force defending against a battalion size attacking force is approximately four CPU minutes on the IBM 3033 computer.

The basic conceptual difficulties found in this thesis are summarized in Figure 1. The numerical values for the



attrition rate coefficients in the deterministic Lanchester-type model are assumed to be the same as those for a corresponding continuous-time Markov chain model. With this assumption, maximum likelihood estimators (MLE's) can be developed for the Markov chain model coefficients. Specific data needed for the MLE computations is extracted from the high resolution Monte Carlo simulation and used to compute "estimated" coefficient values. These values for the continuous time Markov chain model are then substituted into the "analogous" deterministic Lanchester-type model.

Constructing a Lanchester-type attrition model such as that proposed in this thesis is of significant value. With respect to the hierarchy of models concept [Ref. 1], it could possibly fill the requirement as a 'hook' or link between STAR and low resolution models that exist at higher levels in the pyramid of models. However, possibly the most important contribution this model can make is as a filter model for STAR to reduce costs and time to run the many variations of a scenario in STAR. To explain further, consider the upcoming mortar study. To conduct such a study many runs/replications of a battle using the STAR model will have to be made. These numerous runs are required to compare various types of mortars, various types of force mixes,



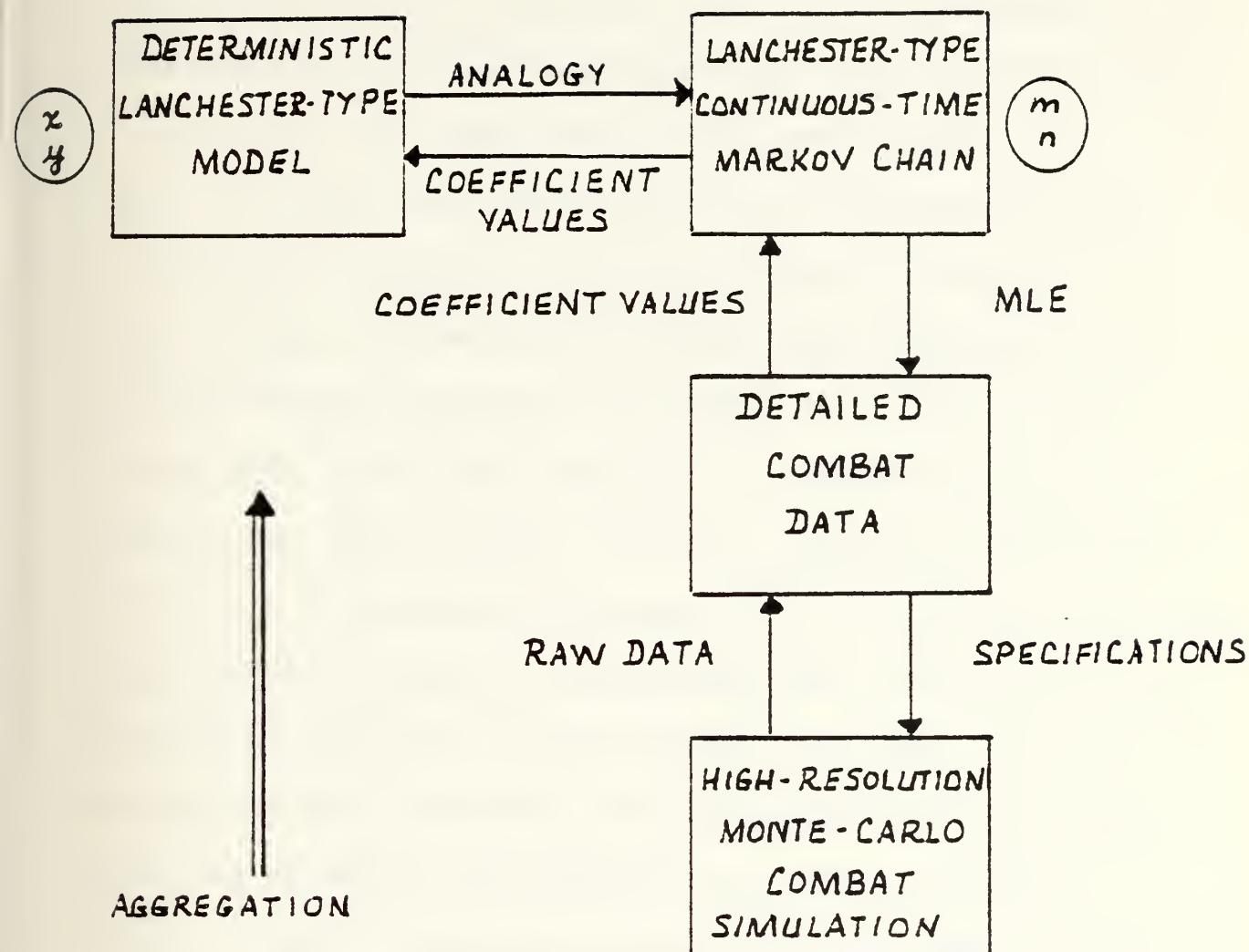


Figure 1: Relationships of Models  
 weapon mixes, and scenarios. Since STAR is a Monte Carlo  
 simulation, variance-reducing replications are required.





This requires significant computer time at a significant cost. By using a simpler analytical model which produces comparable output to a STAR run, many force mixes/weapon mixes/scenarios can be eliminated from further consideration at a minimal cost. STAR can then be used to concentrate only on the more promising options for force/weapons mixes.

This thesis records the progress made in developing the small, simple, Lanchester-type combat model discussed above. It also lays the foundation for future work on this model. Chapter 2 of this thesis provides an introduction to Lanchester-type combat models. Chapter 3 outlines the development of the Deterministic Aggregated Model of STAR on the Apple computer (DAMSTAC), which represents the first step in building an analytical model comparable to STAR. Chapter 4 explores various Lanchester attrition rate functional forms which may be used in the DAMSTAC or in future generation models. Chapter 5 details some desired enhancements of the model, while Chapter 6 discusses the work required to transition from the current homogeneous force DAMSTAC model to a more realistic, albeit more complicated heterogeneous model. Chapter 7 contains the concluding remarks.

Appendix A lists the variables used in the computer program for the DAMSTAC model. Appendix B lists some notes of



interest concerning the program and model, which may not be apparent to the reader. Appendix C discusses the utility programs developed to support the model. Appendix D is a discussion of additional work done by the authors in the form of a computer model that explicitly plays the terrain effect. Appendix E consists of work done by two other students on a postprocessor which supports the computational requirements of the model and acts as an interface between STAR and the model. Finally, Appendix F contains the computer listings of all programs written for this thesis.



## II. HISTORICAL BACKGROUND

Lanchester-type combat models are analytical models in which differential equations are used to express the rate of change of force levels to represent the effects of the attrition process. The concept of representing attrition effects in land warfare with such mathematical equations was originated by F. W. Lanchester in 1914 in order to quantitatively justify concentration of forces.

Lanchester hypothesized that under conditions of "modern warfare" attrition between two homogeneous forces, each using "aimed" fire, could be modelled by:

$$dx/dt = -ay(t) \quad \text{with } x(0) = x_0$$

$$dy/dt = -bx(t) \quad \text{with } y(0) = y_0$$

where  $x(t)$  and  $y(t)$  are the number of X and Y firers alive at time  $t$ , and  $a$  and  $b$  are positive constants that are called Lanchester attrition-rate coefficients. The constant 'a' represents the effectiveness of an x firer in killing y targets per unit of time and 'b' represents the equivalent



effectiveness of the  $y$  firers. The equations written above are usually called "Lanchester's equations for modern warfare". Clearly, these functional forms for attrition rates that Lanchester developed are directly proportional to the attrition rate coefficients and the number of firers from the opposing force. The assumptions that must be made in order to use Lanchester's aimed fire equations to model combat attrition are very restrictive. These assumptions can be stated as follows [Ref. 2]:

1. Two homogeneous forces are engaged in combat;
2. Each unit on either side is within weapon range of all units on the other side;
3. The effects of successive rounds in the target area are independent;
4. Each unit is sufficiently well aware of the location and condition of all enemy units so that it engages only live enemy units (one at a time) and kills them at a constant rate, which does not depend on the enemy force level. When an enemy target is killed, search begins for a new target, with the rate of acquiring a new enemy target being independent of the enemy force level;
5. Fire is uniformly distributed over surviving enemy units.





Lanchester also hypothesized that when both sides used "area" fire, the attrition of forces could be modelled by:

$$dx/dt = -axy$$

$$dy/dt = -bxy$$

The first three conditions under which Lanchester's equations for area fire apply are identical to those for the equations for modern warfare, but assumptions 4 and 5 are replaced by [Ref. 3]:

4. Each firing unit is aware only of the general area in which enemy forces are located and fires into this area without feedback about the consequences of its fire;
5. Fire from surviving units is uniformly distributed over the area in which enemy forces are located;
6. Each unit presents the same vulnerable area to enemy fire. This vulnerable area is much larger than the effective area of a single round of enemy fire. Additionally, the number of hits required for a kill obeys a geometric probability law.

The state equation that relates the force levels and does not explicitly contain time for the aimed-fire assumptions is known as Lanchester's Square Law,

$$b(x_0^2 - x^2) = a(y_0^2 - y^2).$$



The state equation for the area fire model yields  
Lanchester's Linear Law,

$$b(x_0 - x) = a(y_0 - y).$$

From these state equations many important results can be deduced, for example, battle outcome prediction conditions. Further analysis of Lanchester's classical equations and their implications will not be done here. Suffice it to say that Lanchester's original work forms the basis for the analytical combat model, with his simple model serving as a point of departure for the more complicated and elaborate analytical models discussed later in this thesis. Readers of this thesis and students who intend to continue with work initiated here should have a sound understanding of Lanchester's basic models before continuing further.

Lanchester's equations for modern warfare and his equations for area fire have, over the years, been thoroughly dissected and analyzed by students of differential equations and students of analytical combat models. One such student was Gordon Clark, a doctoral student at Ohio State University in the late 1960's. He was well aware of the power that simulation models such as Carmonette, a high resolution combat model, had for describing the complex process of combat. However, the major drawback to simulation, as he



perceived it, was that the method was slow and expensive. Clark proposed that the use of an additional model to interpret simulation results would greatly benefit Army studies which required numerous runs with the simulation model. He went on to develop this analytical model which he called the Combat Analysis Model (COMAN). This much simpler and faster running model would greatly reduce computer execution time and costs, and could serve as a filter model for Carmonette. A similar approach to Clark's methodology in developing COMAN will be used here to develop the analytical model for STAR. The next chapter details the first steps taken to build the analytical combat model for STAR.



### III. DAMSTAC MODEL

The aggregated force-on-force analytical model is an integral part of combat modelling and serves several significant purposes. With the high cost of computer time and the limited computer core storage available to most military users, the analytical combat model offers a viable alternative to detailed high resolution simulations.

Analytical combat models can be used in a stand alone configuration or in conjunction with a high resolution simulation. In the stand alone mode, the models are usually "transparent", or, in other words, easy to understand. They are also small, quick but most importantly, they increase the user's understanding of the process of combat. In conjunction with high resolution combat simulations, the analytical model offers, as Gordon Clark states in his doctoral thesis, the opportunity to "extrapolate the results of the combat simulation to predict the outcome from force mixes that were not explicitly simulated." In this way it can act as a filter to eliminate certain force mixes from further investigation. Also, Clark identifies another use for it as "an integral component of a large unit model to predict the outcome from individual unit actions." [Ref. 4]





A major objective of this thesis was to build a simple aggregated combat model on the Apple II microcomputer. The input parameters for the model were estimated using the output data from a STAR run. This concept of estimating the attrition rate coefficients involved additional work in developing a data postprocessor compatible with STAR, and significant effort in the statistical analysis of the information provided by the postprocessor.

There are several reasons why the Apple II computer was chosen for the development of the model rather than a main frame computer. First, the need exists for a 'portable' model that is easily accessible to the Army analyst. A desk top type system that can run a model quickly and with minimum setup time will be a valuable asset to the analyst. With the Apple II computer gaining wider acceptance in the Army for various uses, the accessibility of a model on such a system is greatly increased.

Second, the nature of the model is such that it lends itself to a small system format. The aggregated form of the model reduces the required core storage from that required by a high resolution model. The concept of DAMSTAC is to serve as a filter model to weed out unacceptable force mixes or scenarios before turning to a high resolution model. The



idea here is to reduce the time and cost of running numerous iterations of a large, high resolution model on a main frame computer.

Third, the cost of a computer system to support the model is certainly economical. At a cost of under \$3000, the Apple II computer system with a model such as DAMSTAC provides a powerful analytical tool for a minimal cost, certainly in relation to the cost of a main frame computer.

Fourth, the Apple II has the capability to provide additional analysis functions on the output of the model. With such programs as Apple Plot and available commercial statistical and numerical analysis packages, most of the needed analytical work can be accomplished on the Apple II computer. This can result in additional savings in time by eliminating the requirement to transfer any data from one system to another.

The laurels cast on the Apple II should not go without some discussion of its limitations. The Apple II is limited in capacity to 64 kilobytes of Random Access Memory storage space. So, essentially the model must be able to work within the amount of core storage. There are methods of working around this problem, if it arises, but this will usually create a new problem or limitation. For example,



some of the data or a part of the program can be kept on the storage diskette and put into computer memory only when it is needed. This saves space in the computer's memory but increases the run time of the model due to the time required to access the diskette to retrieve the required information.

This raises another limitation of the Apple II--its run time. Compared to a main frame computer, the Apple II is very slow. This is, however, relatively speaking since computer time is normally measured in milliseconds and nanoseconds. For the analyst waiting for the output from DAMSTAC, the model on the Apple II would take about four to ten minutes to run. This is probably acceptable for most analysts.

#### A. SCENARIO

The model portrays a battle between a RED tank battalion attacking a BLUE tank company in the 10 x 10 KM Fulda Gap (Keyhole) terrain. See Figure 2 for the terrain map.

The BLUE defensive positions and the RED positions along with their attack routes (coordinating points) are provided in Table 1. The RED units attack along three preplanned attack routes toward the BLUE defensive positions. Grid coordinates for unit locations and coordinating points were computed as the centroid of the elements of the unit. In





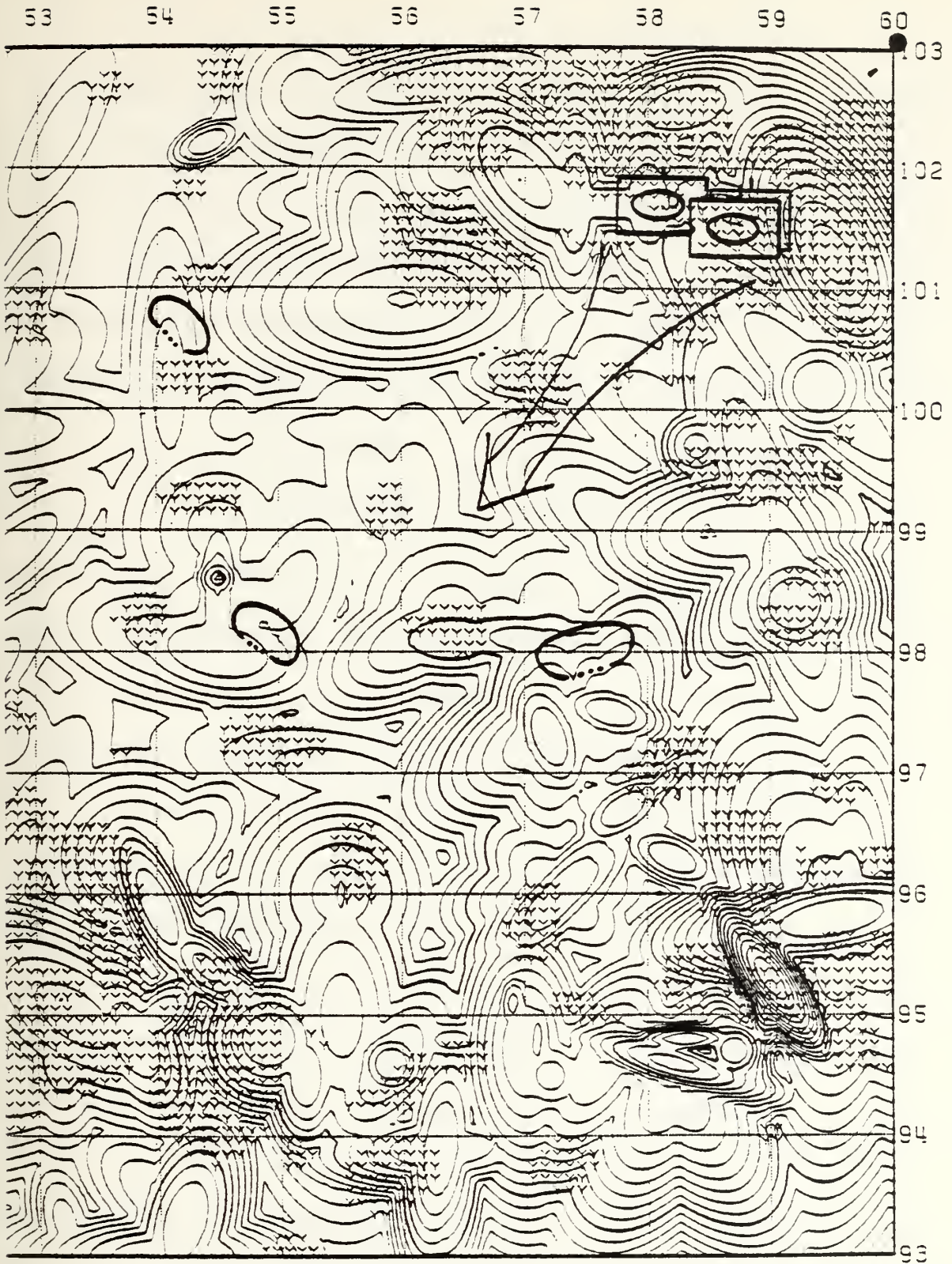


Figure 2: Terrain Map





Star's data base, each tank has its own individual location. For example, BLUE unit 1 has four different locations associated with the it, each one corresponding to a tank in the unit. The centroid of the unit was taken to be the average of these grid coordinates. Thus, the initial location for BLUE unit 1 in Table 1 is the average of these coordinates:

54150 100690	54150 100620
54190 100520	54160 100790

The rate of RED advance is a constant but specified by the user. BLUE units can move to alternate positions at a rate designated by the user. However, for this scenario, BLUE units remain stationary for the entire battle.

To obtain the raw output data that would correctly reflect the above scenario, it was necessary to "turn off" many of the submodels of STAR. For example, the Field Artillery module was shut off by scheduling the first fire mission well after the battle ended. Weapon systems other than tanks within the fighting units were rendered useless by setting their ammunition counts (basic loads) to zero. Additionally, the communications and the Air Defense modules were not played. After all of these preliminary actions were taken, the result was a battle exclusively between tanks. This effort worked well to reduce a complicated,



heterogeneous force battle to a simple homogeneous force battle. One minor problem arose, however, when a weapon system other than a tank was detected and fired on when, by the scenario, it did not even exist. The effects of this target acquisition and engagement were considered insignificant and were disregarded.

Table 1: UNIT LOCATIONS/COORDINATING POINTS

<u>BLUE</u>	<u>X-COORD</u>	<u>Y-COORD</u>	<u>SIZE</u>	<u>REMARKS</u>
UNIT 1	54163	100655	4	initial location
UNIT 2	54788	98120	4	initial location
UNIT 3	57448	97893	4	initial location

<u>RED</u>	<u>X-COORD</u>	<u>Y-COORD</u>	<u>SIZE</u>	<u>REMARKS</u>
UNIT 1	58727 52000	101491 96000	10	initial location coordinating pt
UNIT 2	58110 52000	101696 96000	10	initial location coordinating pt
UNIT 3	58727 52000	101491 96000	10	initial location coordinating pt

## B. ASSUMPTIONS

The attrition rate functional form chosen for the DAMSTAC model, which will be discussed later in this thesis, requires the following assumptions.

1. The conditional kill rates,  $\alpha$  and  $\beta$ , are constant and independent of time if an individual firer has at least one acquired target. If there are no acquired targets,



the kill rates are zero.

2.  $P$  and  $q$ , the probabilities of nondetection, are assumed to be constant functions of time, that they are independent of the force size and the number of acquired targets, and that the probabilities  $p$  and  $q$  are equal for all x-firer/y-target and y-firer/x-target combinations respectively.

3. Synergistic effects are neglected, therefore, the actual force attrition rate is equal to the sum of the individual kill rates for the opposing forces.

Additionally, the assumptions listed below are designed to remove the distractions of a complicated scenario and to make the initial model easier to understand:

1. All units have point locations; ie. a battalion is represented by a grid coordinate and all calculations for the battalion are made from that location.

2. Units are homogeneous. That is, they are composed of identical firing elements/weapons systems.

3. Fire is uniformly distributed over surviving enemy targets within range.

4. Sufficient supplies of ammunition for both sides exist for the duration of the battle.

5. Units move at a constant rate of speed.



## C. SYNOPSIS OF THE COMPUTER MODEL

The DAMSTAC computer program is a modular type program written in the Applesoft BASIC language. The program accesses external data files as a source of input of initial data for the two forces. These data files are produced by the user with the help of the Force Maker utility program described in Appendix C. Additionally, the program has the capability to make output files that can be stored on a diskette and accessed by the user with the Results Reader utility program, also described in Appendix C. Results Reader will print the output to the screen or to a printer.

A copy of the program for the model is included as Listing A in Appendix F. A sample run of the model including user inputs is included as Figure 3. Flow charts of the main program and subroutines are included as Figure 4, Figure 6, and Figure 7.

### 1. Initialization of Arrays and Variables

Lines 30 thru 170 dimension the arrays and matrices and initialize hardwired data. Dimensions are set to handle up to five units in each force and up to ten coordinating points, including the initial location, for each unit. The user can modify these capacities by changing the dimensions of the appropriate variables.





```

1RUN
NAME OF FILE FOR BLUE DATA? THESIS
1
54163          100655
SIZE OF BLUE UNIT 174
1
54788          98120
SIZE OF BLUE UNIT 174
1
57448          97893
SIZE OF BLUE UNIT 174

NAME OF FILE FOR RED DATA? THESIS
SIZE OF RED UNIT 1710
SIZE OF RED UNIT 1710
SIZE OF RED UNIT 1710

DO YOU WANT THE PRINTER ON? (Y/N) Y

```

TIME	BLUE	RED
0	12	30
30	12	30
60	12	30
90	12	30
120	12	30
150	12	30
180	12	30
210	12	30
240	12	30
270	12	30
300	11.5695362	29.1743717
330	10.858762	28.4987136
360	10.1687086	27.1036729
390	9.61458731	25.9203808
420	9.37784103	25.1618404
450	9.17400928	24.6831241
480	9.99690578	24.1710725
510	8.8417791	23.7182286
540	8.70492405	23.3071843
570	8.63779153	22.4150871
600	8.48823959	22.1081593
630	8.36874557	21.8237029
660	8.36874557	21.8237029
690	8.36874557	21.8237029
720	8.36874557	21.8237029
750	8.36874557	21.8237029
780	8.36874557	21.8237029
810	7.81867949	21.0780807

Figure 3: Sample Run of the Model



Lines 180 thru 350 read BLUE force data from a file to include the number of units, initial locations, any coordinating points, and rates of advance, and compute total force level based on user input of the unit force levels. The time increment (DT) is set to 30 seconds while the maximum time of the battle (MT) is set to 1500 seconds. These values are, of course, adjustable by changing them in line 80. For both forces, the breakpoint criteria is set at 0.3 of the force level and movement criteria is set at 0.5 of the unit strength, even though the movement criteria was not used for any runs of the model.

Lines 360 thru 520 perform the same operations for the RED forces as lines 180 thru 350 perform for the BLUE forces.

Lines 530 and 600 ask if the printer should be turned on or off and calls the printout subroutine to print the initial data.

## 2. Main Program (lines 610-780)

The main program performs these operations:

increments the time,

checks if the time exceeds the max time,

calls the movement and attrition subroutines,

recomputes current total force levels after attrition, and



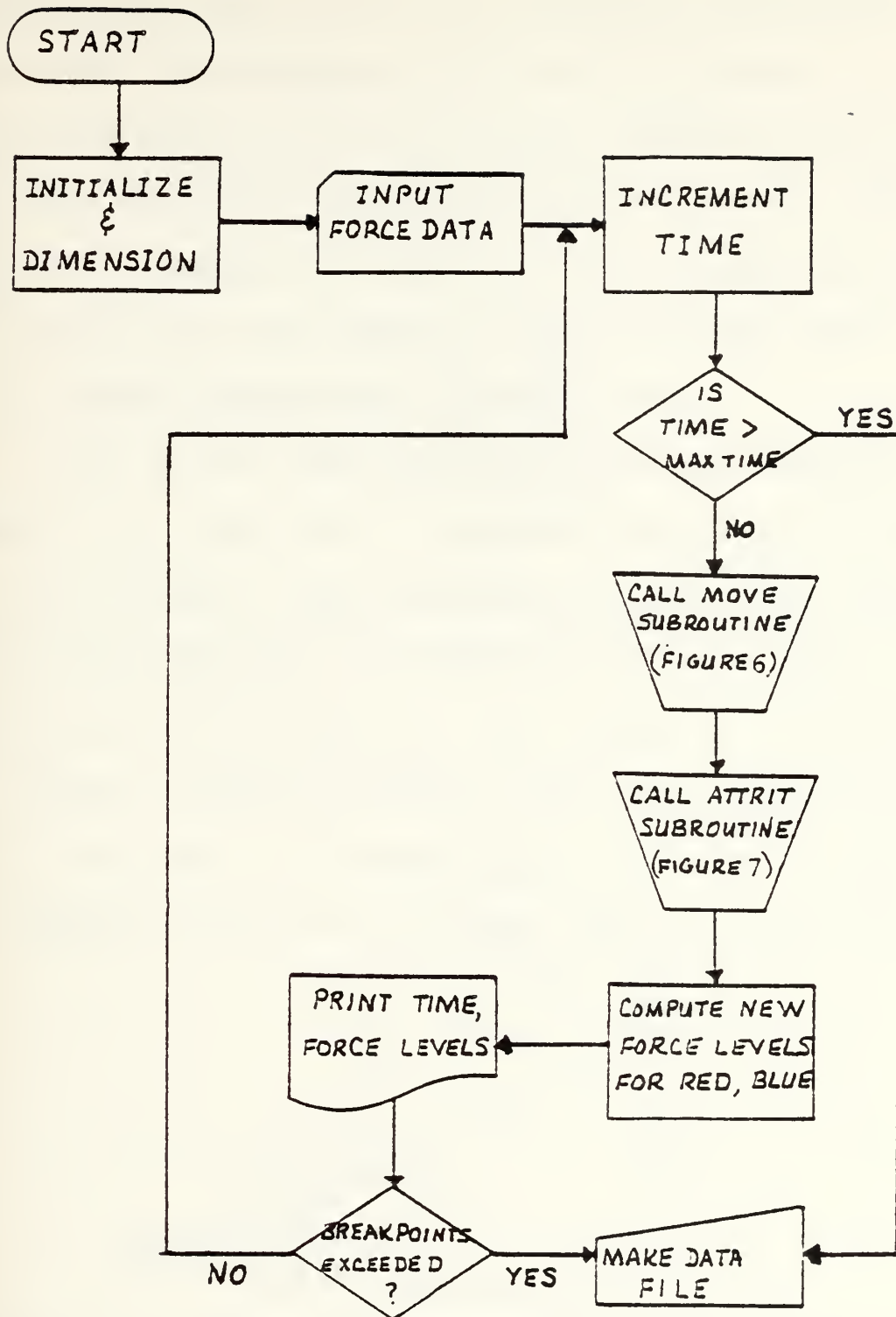


Figure 4: Flow Chart of the Main Program



checks force levels against the designated breakpoints for each force, to determine if the battle has ended. If the breakpoints or the max time are exceeded, the battle terminates and the program prints the force levels. Additionally the program will write the force levels for each time interval onto the diskette. (lines 1470 thru 1580)

### 3. Movement Subroutine (lines 790-1160)

Both RED and BLUE forces are capable of moving. Movement of the BLUE force is nullified by setting its movement rate to zero in the initialization part of the program. The movement subroutine uses basic geometry to compute new coordinates for the moving unit (see Figure 5). The movement process is based on moving a unit from one coordinating point to the next in a straight line. The amount of movement depends on the rate of movement (BR(I) or RR(I)) and

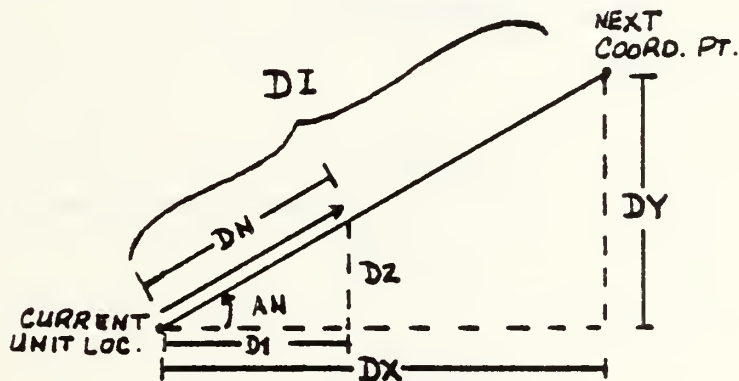


Figure 5: Geometric Representation of Unit Movement





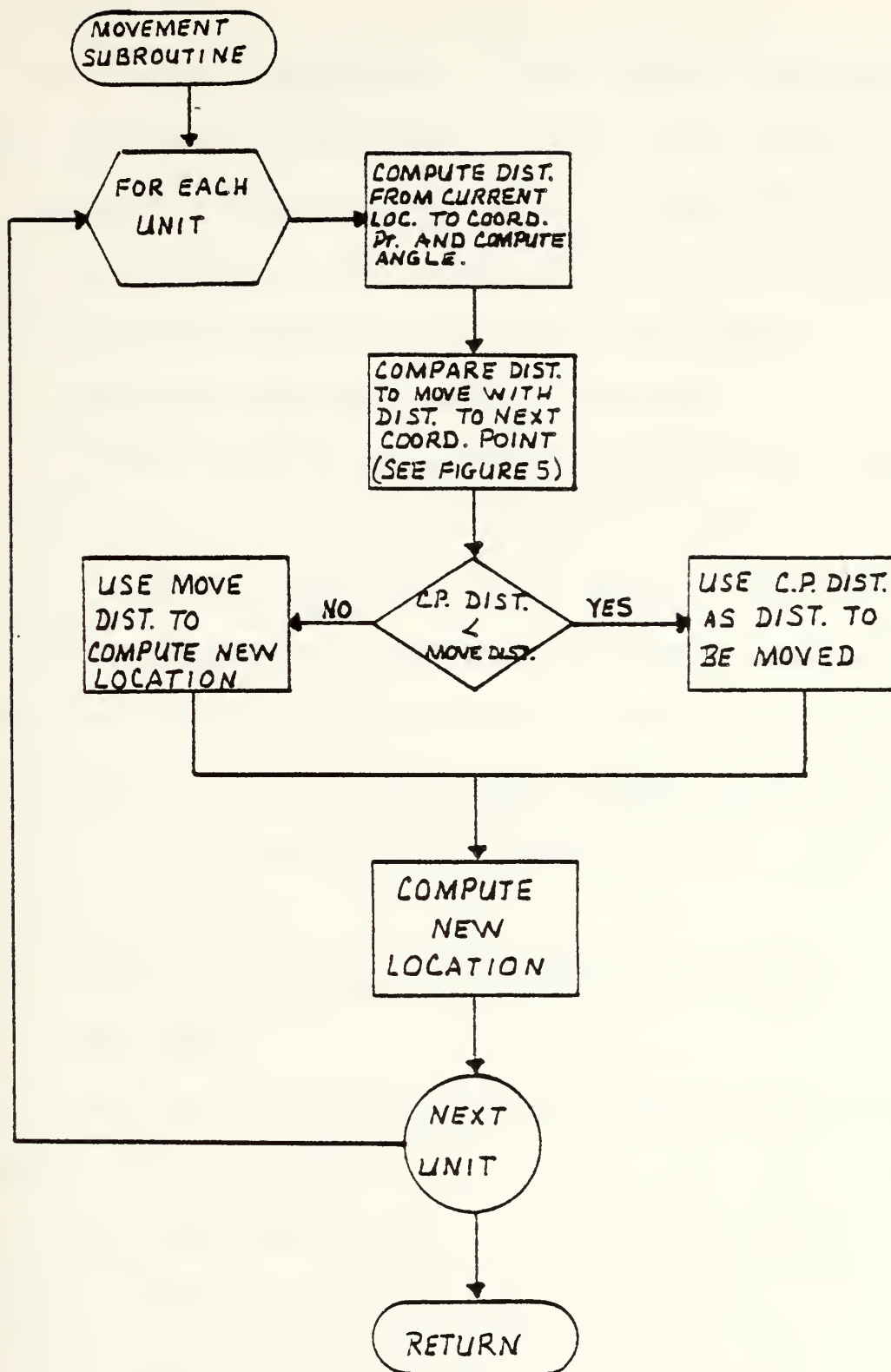


Figure 6: Flow Chart of the Movement Subroutine



the time interval length (DT). If the distance computed is farther than the next coordinating point, only movement to the coordinating point is accomplished. Lines 800 to 970 perform computations to move RED forces while Lines 980 to 1150 perform the same computations for BLUE forces.

4. Attrition Subroutine (lines 1170-1480)

A range check is made for each firer/target combination to insure the units are within firing range. If so, attrition caused by that firer on the target is computed. Next total attrition for each unit is computed based on the partial attritions of the firers as a fraction of their force levels. In other words, when a firer is firing at 3 enemy units, each target unit receives 1/3 of the firer's fire power.

5. Printout Subroutine (lines 1490-1530 & lines 1760-1940)

There are two different output formats used in the program. The first (lines 1490 to 1530) prints only a summary of the total force levels for both forces for each time interval. This is the same data that is saved to a file by the final portion of the program. The second format (lines 1760 to 1940) prints out the units of each force with their



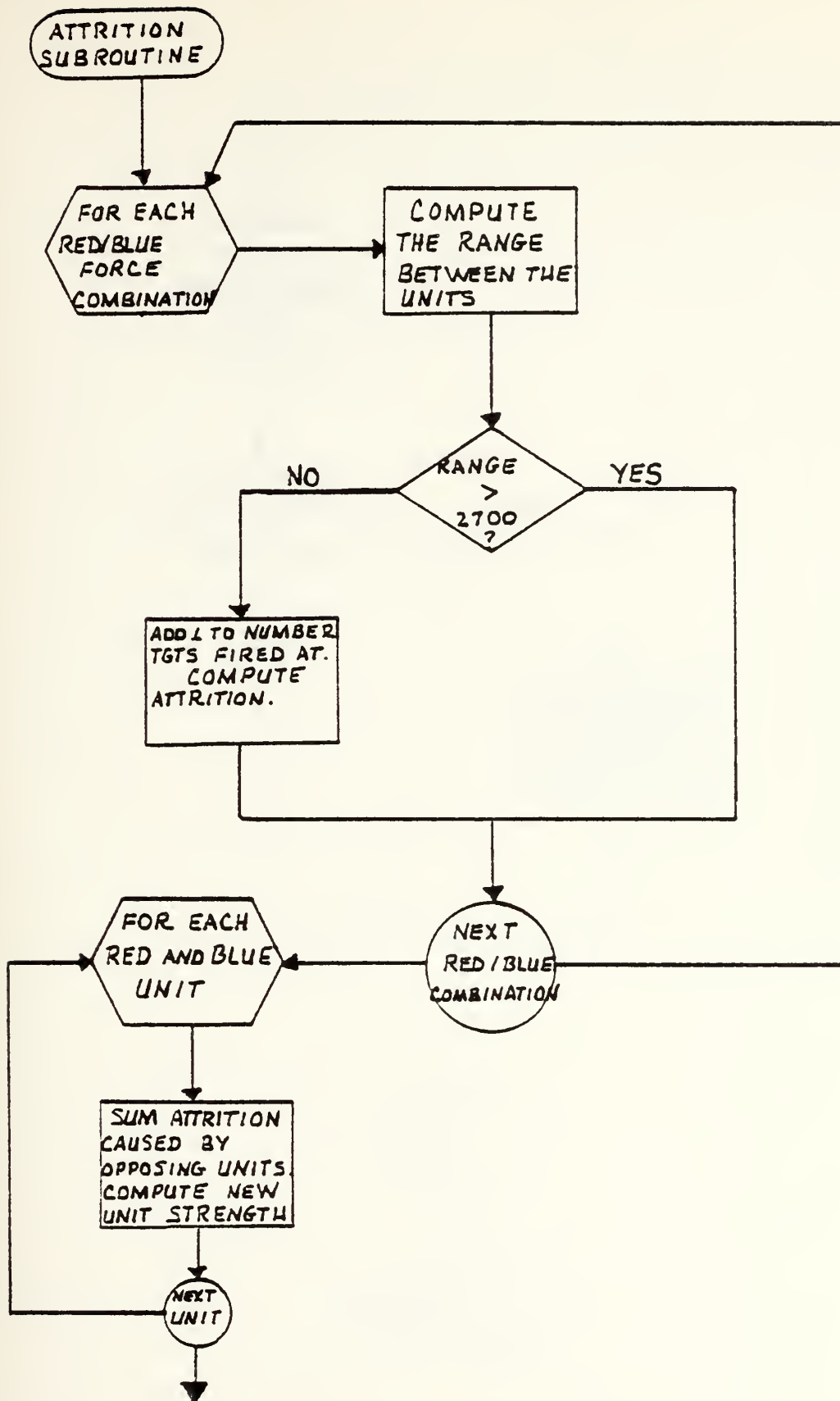
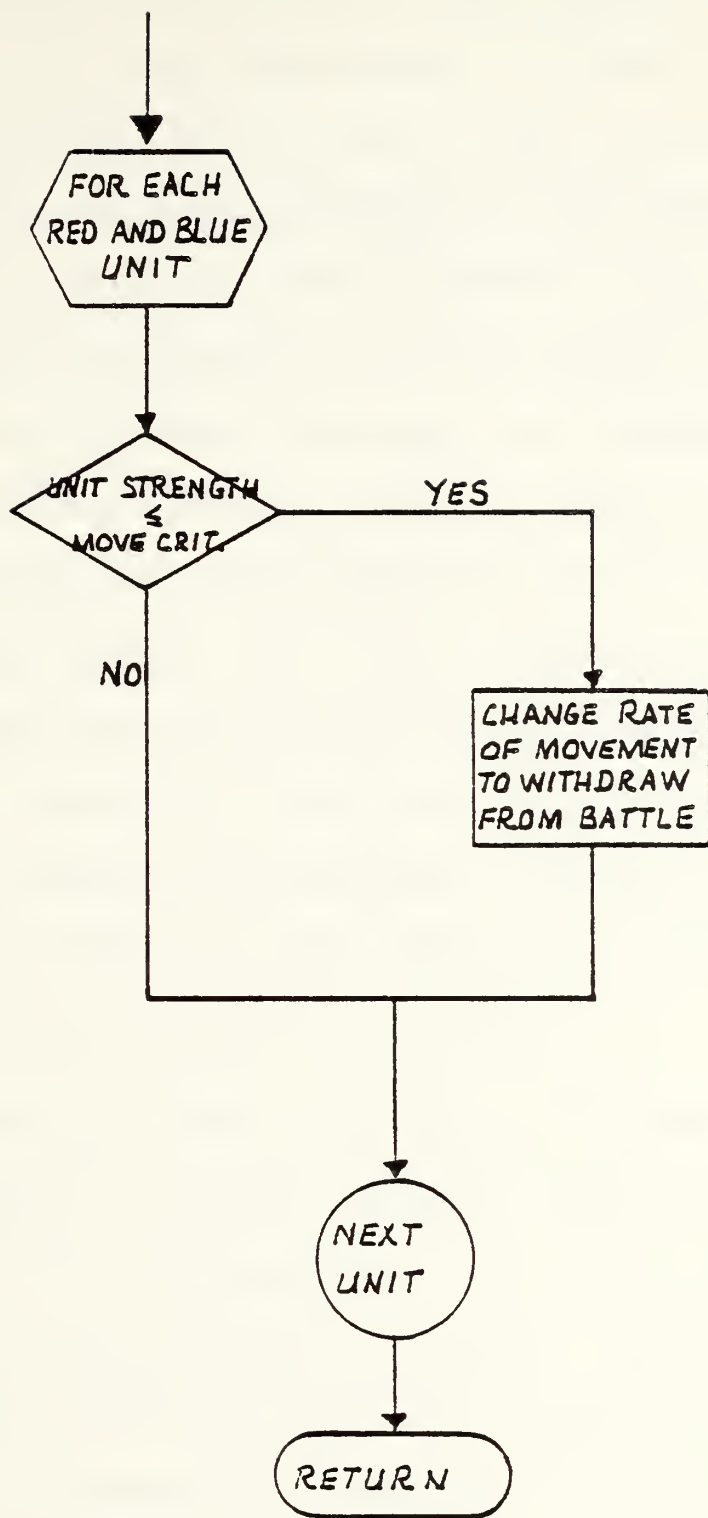


Figure 7: Flow Chart of the Attrition Subroutine









current locations and strengths. This format allows the user to see which unit, specifically, is being attritted and the grid coordinates of that unit at the time of attrition.

#### 6. Output File Making Subroutine (lines 1540-1750)

This subroutine allows the user to make a file of the output from the current run of the program. This routine actually produces two files, one consisting of the attrition rate coefficients and probabilities of non-acquisition, and the second containing the time and force levels of both forces at that time. These files are seperated so that the second file can be used with the APPLEPLOT program to produce a graph of the two force levels as a function of time. This file has the postscript, ".RESULTS", added to its file name, while the first file with the attrition rate coefficients has the postscript ".COEFS".

#### D. METHODOLOGY FOR COMPUTING PARAMETER ESTIMATES

The process of building a computer simulation combat model requires the development of methodologies for modelling the various aspects of combat. Constructing a force-on-force attrition model requires methods for consolidating combat phenomena into simplified algorithms with coefficients representing one or more facets of combat. This section discusses one significant part of the



force-on-force attrition model: the methodology for estimating the attrition rate coefficients in the Lanchester type attrition rate equations.

In deriving the equations for the attrition rates ( $dx/dt$  and  $dy/dt$ ), it is necessary to understand the processes that must occur to cause a firer to inflict attrition. These key processes can be summarized as:

- the environmental process;
- the target acquisition process;
- the target engagement process.

The environmental process involves the terrain and weather factors that affect firer/target line of sight (LOS). The target acquisition process represents the visible capability of the firer to detect a target on the battlefield, while the target engagement process describes the firer's ability to hit and kill an acquired target. These three processes will all be represented by the attrition rate coefficient,  $A$ , in the attrition rate equation. This coefficient will be broken down into its three components which describe mathematically the phenomena of the three processes. The three components are:

$P_v$  = the probability that a target is visible to the firer  
(environmental process)



$P_a$  = the probability that a visible target is acquired  
(target acquisition process)

$\alpha$  = the casualty rate at which a firer attrits the  
acquired target (target engagement process)

$\alpha$  should not be confused with  $A$ , the attrition rate  
coefficient, of which  $\alpha$  is a factor. The attrition rate  
equation may be represented in words by:

$$dx/dt = -[P(\text{tgt is visible})][P(\text{tgt is acquired})][\text{casualty rate}]$$

The second probability above can be broken down further to  
 $P(\text{tgt is acquired} \mid \text{tgt is visible})$ . Note that this is a  
conditional probability since it is assumed that the target  
must be visible to be acquired. By identifying the  
mathematical expressions for each of these components of the  
attrition rate coefficient, the attrition rate equation can  
be obtained.

### 1. The Environmental Process

There are generally two ways to represent line of  
sight in a model:

as a mathematical simulation of actual terrain;

as a stochastic process.

The mathematical simulation method normally involves a  
digital representation of terrain elevation over a segment  
of the terrain. The elevations of the segments between the



firer and the target are used to determine if line of sight exists. Virtually all high resolution models use this method, or variations of it, to determine line of sight. STAR uses a different form of mathematical simulation to represent terrain. This is called functional terrain, in which hills and forests are represented by elliptical contours of elevation. Hills are modelled by describing them in terms of bivariate normal equations with varying parameters for each hill. Forests or built-up areas are represented by an elliptical pattern on the ground again with varying parameters for each forest.

For a low resolution or highly aggregated model, the mathematical simulation method for line of sight is usually not practical or desirable in terms of core space and computation time required. Therefore, the second method, in which LOS is represented as a stochastic process, is used. The concept of this process is as follows. The effect of terrain on the process of line of sight is that a target falls into one of two categories or states: either it is visible or it is invisible.

Assuming a steady-state situation for the terrain, probabilities can be assigned to each of these two states. These probabilities represent the percentage of time that





the target will be in that state (visible or invisible) for that terrain over a reasonable amount of time. Graphically, the states of the target can be represented by the diagram in Figure 8.

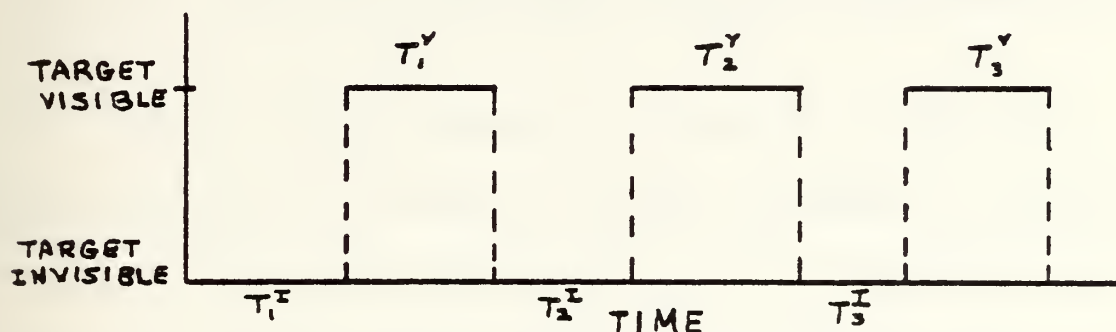


Figure 8: Two-state Stochastic Graph of Intervisibility

Since this is a stochastic process, there is an exponential distribution associated with each of the two states. This distribution represents the time between two occurrences of the same state. On the graph in Figure 8, the time between the end of  $T_1^V$  and the start of  $T_2^V$  is exponentially distributed with mean,  $\eta$ . Likewise, the time between the end of  $T_1^I$  and the start of  $T_2^I$  is exponentially distributed with mean,  $\mu$ . Graphically, this can be represented by Figure 9, where the circles represent the two states, visibility and invisibility, and the arrows represent the transition from one state to the other at the given rate.



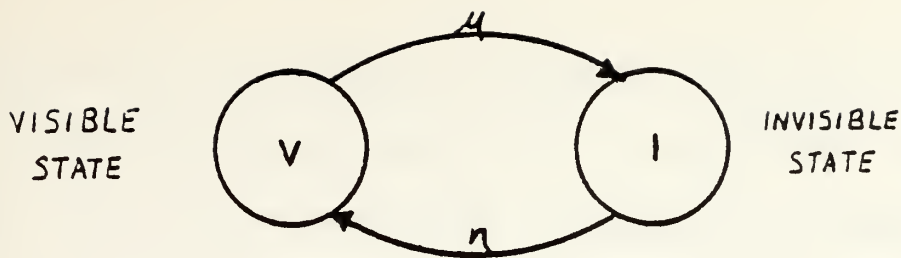


Figure 9: Two-state Stochastic Model of Intervisibility

The attrition caused by a firer on a target can occur only when the target is visible (assuming no attrition from wild, blind shots or indirect fire). Therefore, the attrition rate is a function of the probability that the target is visible to the firer. This probability will be denoted as  $p_v$ , and can be expressed as the proportion of time that the target is in the visible state in a steady state situation,  $p_v = \frac{\eta}{\eta + \mu}$ .

## 2. The Target Acquisition Process

Assuming now that line of sight exists between a firer and a target, the process of target acquisition must now be represented. There are two primary modes of target acquisition:

Serial acquisition, and

Parallel acquisition.

In the serial acquisition process, targets are acquired between engagements. That is, in concept, the firer is



concentrating on the engaged target and does not or is not able to acquire other targets on the battlefield. Any additional acquisitions made prior to engaging the current target are lost and must be re-acquired after the current engagement has ended. Examples of firers who use serial acquisition are:

any firer who is "buttoned up" and has his field of view narrowed to a thin band;

wire guided missiles/anti-tank systems.

In the parallel acquisition mode, the firer maintains his list of acquired targets throughout an engagement (except those lost through loss of line of sight). Thus, when an engagement has ended, by the target being killed or loss of line of sight, the firer may immediately engage a target that was previously acquired and is still a valid target. All systems which do not use serial acquisition are assumed to use the parallel mode.

For purposes of this thesis, all firers are assumed to use parallel acquisition. Therefore, serial acquisition will not be discussed any further. The reader should note that the serial acquisition process does have validity in modelling action on the battlefield, and should be considered in future enhancements of this model.



To explain the derivation of the target acquisition portion of the attrition rate equation, the diagram in Figure 9 must be modified to that in Figure 10.

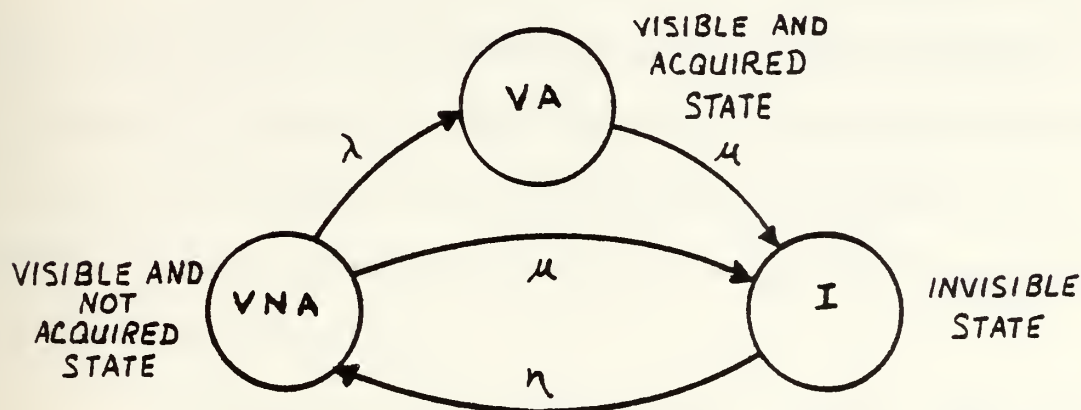


Figure 10: Three-state Stochastic Model of Intervisibility

The two-state stochastic process has been changed to a three-state process by dividing the visible state into the visible-not acquired state (VNA) and the visible-acquired state (VA). What has occurred is that a target can move from the visible-unacquired state to the visible acquired state at a rate  $\lambda$ . Since both of these states comprise the visibility state in total, the rate of moving from either of them to the invisibility state remains at  $\mu$ . Notice that there is no direct transition from the invisible state to the visible-acquired state. This is only a matter of representation, since it is assumed that no more than one event, ie. moving to a new state, will occur during a time





increment. Thus, the situation described can still be represented by Figure 10.

Another point of interest in this diagram is the fact that there is no transition from visible-acquired to visible-not acquired. This implies the assumption that once a target is acquired, it remains acquired unless it is killed or line of sight is lost, in which case it transfers to the invisible state.

To determine the effect of the target acquisition process on the attrition rate, the probability that a target is acquired must be determined. From Figure 10, and using the same concept of a stochastic process as that used in section III-D-1, the equation can be written

$$P_a(\text{tgt acquired}) = \frac{\lambda}{\lambda + \mu} . \quad (1)$$

This should more properly be stated as the probability that a target is acquired given that it is visible, since this is actually a conditional probability with the state of acquisition being dependent on the target being visible.

Therefore, the probability that a target is visible and acquired in the steady state is:

$$\begin{aligned} P_{va} &= P(\text{tgt vis \& acq}) \\ &= P_a(\text{tgt acq} | \text{tgt vis}) P_v(\text{tgt vis}) \quad (2) \\ &= \left( \frac{\lambda}{\lambda + \mu} \right) \left( \frac{\eta}{\eta + \mu} \right) \end{aligned}$$



The implications of this equation will be discussed later in Chapter V.

### 3. Formulating the Attrition-rate Equation

Using equation (2) in the attrition-rate equation, the attrition rate of a single firer on a single target can be summarized using expected values as:

$$dx/dt = -P_{va} \alpha \quad (3)$$

That is, the attrition rate equals the rate of killing an acquired target times the probability that a target is visible and acquired. However, since there are likely to be more than one firer and more than one target on the battlefield, this equation must be modified to reflect this.

If a firer is going to cause attrition on his targets, he must be able to acquire one or more of these targets. For firer  $y_1$  with  $x$  targets, the probability that  $y_1$  acquires one or more targets is just one minus the probability that he acquires no targets. Assuming the same probability of acquiring any of the targets, the probability of acquiring none of the targets is  $(1 - P_{va})^x$ . Therefore,

$$P_{a_{y_1}} = 1 - (1 - P_{va})^x \quad (4)$$



The attrition rate now becomes

$$dx/dt = -P_{a_{xy}} \alpha \quad (5)$$

for a single firer against  $x$  targets. Since there are more than one firer on the battlefield, each assumed to be acting independent in this process, the attrition rate in equation (5) must be multiplied by the number of firers ( $y$ ) and the equation is now complete:

$$dx/dt = -P_{a_{xy}} \alpha y . \quad (6)$$

In terms of the probability of acquiring a target, this equation can be written as:

$$dx/dt = -(1 - (1 - P_{va})^x) \alpha y . \quad (7)$$

This is the same equation which Clark uses in his COMAN model, that uses results from a high resolution model to estimate the value for the conditional casualty rate and the probability that a target is not acquired. Henceforth,  $(1 - P_{va})$  will be referred to as  $p$  for RED firer/BLUE target combinations (or  $q$  for a BLUE firer/RED target combination).

#### 4. The Target Engagement Process (Bonder vs Clark)

The target engagement process can be modelled in its most detailed form, as in the high resolution model, or in



its simplest form, as in the aggregated, analytical model. The high resolution model, such as STAR, includes explicit representation of every factor that is involved in the process of aiming at, firing at, hitting, and killing a target. These factors include:

- weapon system characteristics;
- weapon/ammunition type characteristics;
- target characteristics such as size, shape, vulnerability, etc.

In contrast, the low resolution, aggregated model represents the engagement process by one value--the attrition rate coefficient. This is the method to be employed in the model presented here. The task now is to develop a method to accurately estimate this coefficient for use in the attrition rate equation. Note that we are actually talking about two attrition rate coefficients and two equations. The derivation and method for estimating one is the same as the other, so for purposes of the discussion, references to an attrition rate coefficient will be in the singular.

There are presently two basic approaches to the problem of estimating attrition rate coefficients for parallel acquisition and stochastic line of sight. The first is





the use of the independent analytical model, involving weapon system characteristics and the use of algorithms to determine the expected time for a firer to kill a single target. The attrition coefficients are then the reciprocal of these expected times. This method will be referred to as Bonder's method after Seth Bonder who has used it extensively in his combat models such as VECTOR II.

The second method is the fitted-parameter analytical model, involving the use of a separate high resolution, Monte Carlo combat simulation to produce data to determine a maximum likelihood estimate of the attrition coefficients. This method will be referred to as Clark's method, since Gordon Clark popularized it in his doctoral thesis and in the development of the Combat Analysis Model (COMAN).

Most of this section involves a discussion of Clark's method and the practical application of it. However, in order to provide a contrast to that method, a short description of Bonder's method will be provided.

In general, the concept of Bonder's method is to produce an algorithm representing the expected time that it takes a firer to kill a single target. The elements of this algorithm include computations for line of sight, target acquisition, target selection, and the killing process.



Each element accounts for a certain amount of time in the expected time to kill a target. This entire process is seen by Bonder as a Markov renewal process where the outcome of a round fired is dependent only on the outcome of the previous round. By using weapon systems characteristics data as raw input, times to acquire, select, and kill a target can be determined and used in the algorithm for expected time to kill a target.

Bonder's method uses an independent, analytical model requiring a large data base of factors, such as range dependent weapon system characteristics, quantifications of line of sight and target acquisition parameters, to support the computation of the attrition rate coefficient.

A detailed explanation of Bonder's method for estimating the attrition rate coefficients can be found in the basic documentation for the VECTOR II model [Ref. 5]. Basically, Bonder says that the attrition rate coefficient  $A_{ij}$  is represented in the parallel acquisition mode by  $A_{ij} = Q_{ij} \alpha$ , where  $Q_{ij}$  is the probability that a given group-i weapon is firing at a group-j target.  $Q_{ij}$  can be expressed in terms of the probability that a group-j target is visible and has been detected by a group-i firer. This probability is denoted as  $S_{ij}$ , and the expression for  $Q_{ij}$  is :



$$Q_{ij} = S_{ij} \prod_{j=1}^{j-1} (1 - S_{ij}) \text{ for } j \geq 2 .$$

Assuming homogeneous forces, this equation reduces to

$Q_{ij} = S_{ij}$  , and the i-j subscripts can be eliminated since there is no distinction among types of force elements. His resulting expression for S is identical to that of equation 4 , where  $S_{ij}$  and  $P_{ax}$  are defined the same.

Bonder's expression for the conditional casualty rate,  $\alpha$  , is written as the inverse of the expected time to kill an acquired target. This expression, when further broken down contains elements dependent on the weapon system characteristics, target characteristics, and a number of other subsystem performance parameters. These parameters were determined empirically outside the operational environment of the battlefield and molded together in this predetermined structure to produce the value of the attrition coefficient. This derivation of the attrition coefficient is the point where Bonder's method and Clark's method differ.

Clark's methodology is based on the assumption that the process of attrition in combat is a nonhomogeneous, two independent type Poisson Process where the time between casualties has an exponential distribution with parameter  $\lambda$  , called the total conditional casualty rate. Likewise, the



time between RED casualties and the time between BLUE casualties each has an exponential distribution with parameters  $\lambda_r$  and  $\lambda_b$  respectively, where  $\lambda = \lambda_r + \lambda_b$ . From the theory of Poisson Processes, the probability of a RED casualty occurring is  $\lambda_r/\lambda$ , and the probability of a BLUE casualty occurring is  $\lambda_b/\lambda$ . With this basis, Clark is able to develop a likelihood function in terms of the conditional casualty rates  $\alpha$  and  $\beta$ , of which the casualty rates are functions, ie.,  $\lambda_b = f(\alpha)$  and  $\lambda_r = f(\beta)$ . [Ref. 6] It should be noted that, in order to maintain consistency of terminology, the equations attributable to Clark's work have been adjusted to reflect the definitions presented in this thesis.

Clark also uses the concept that attrition is a function of target acquisition, which depends on the probability of a firer acquiring a target. This concept produces two more parameters which must be estimated:  $p$ , the probability that a BLUE target is not acquired by a RED firer;  $q$ , the probability that a RED target is not acquired by a BLUE firer.

For the functional form in Clark's COMAN model, the equations can be written as:





$$\begin{aligned} f_b &= -\alpha[1 - p^m] \quad \text{with } m(0) = m_0 \\ f_r &= -\beta[1 - q^n] \quad \text{with } n(0) = n_0 \end{aligned} \tag{8}$$

where the parameters are defined by:

$f_b$  = the conditional attrition rate function for BLUE forces

$f_r$  = the conditional attrition rate function for RED forces

$\alpha$  = conditional kill rate for a RED weapon against acquired BLUE targets

$\beta$  = BLUE weapon conditional kill rate corresponding to  $\alpha$

$p$  = probability that a BLUE target is unacquired by an individual RED firer

$q$  = probability that a RED target is unacquired by an individual BLUE firer

$m$  = number of BLUE firers surviving

$n$  = number of RED firers surviving

These functional forms depend directly on the ability of firers to detect targets. To see this, consider just the conditional attrition rate function for the BLUE force,  $f_b$ . The definition of  $p$  implies that the value of  $(1-p^m)$  is the probability that a RED firer has at least one acquired



BLUE target. Therefore, the attrition rate for the BLUE force is the kill rate for acquired targets times the probability of having an acquired target times the number of firers.

It should be noted that Lanchester's classical attrition rate functional forms are special cases of Clark's attrition rate functional forms, and, under appropriate conditions, Clark's equations reduce to Lanchester's equations. When  $p$  and  $q$  are zero, or very nearly zero,

$$f_b = - \alpha (1-0^m) n = - \alpha n \quad (9)$$

and,

$$f_r = - \beta (1-0^n) m = - \beta m \quad (10)$$

which are Lanchester's classical aimed fire equations. When individual targets become increasingly difficult to acquire,  $p$  and  $q$  assume values close to one and it can be proven that in the limit:



$$\dot{f}_b = - \alpha (1-p) mn \quad (11)$$

and,

$$\dot{f}_r = - \beta (1-q) mn \quad (12)$$

If the attrition rate coefficient  $a$  is set equal to  $\alpha(1 - p)$  and the coefficient  $b$  is set equal to  $\beta(1 - q)$ , then the two equations above are identical to Lanchester's equations for area fire.

In his doctoral dissertation, Clark developed the likelihood function for a heterogeneous model, however since the DAMSTAC model assumes homogeneous forces, the necessary equations have been reduced to a simpler form than that derived by Clark. By differentiating the logarithm of the likelihood function with respect to  $p$ , the following equation is derived:

$$\frac{\partial \ln L(p, \alpha)}{\partial p} = - \sum_{k=1}^K \frac{C_k m_{k-1} p^{m_{k-1}-1}}{(1 - p^{m_{k-1}-1})} + \sum_{k=1}^K m_{k-1} p^{m_{k-1}-1} n_{k-1}(t_k - t_{k-1}) = 0 \quad (13)$$

where

$C_k = 0$  if casualty  $k$  is RED



1 if casualty k is BLUE

$m_{k-1}$  = number of BLUE survivors prior to kth casualty

$n_{k-1}$  = number of RED survivors prior to kth casualty

$t_k - t_{k-1}$  = time between casualty k & casualty k-1

Likewise, by differentiating the logarithm of the likelihood function with respect to  $\alpha$ , and by solving for  $\hat{\alpha}$ , a second equation in terms of  $\hat{\beta}$  and  $\hat{\alpha}$  is produced:

$$\hat{\alpha} = \frac{\sum_{k=1}^K C_k}{\sum (1 - \hat{\beta}^{m_{k-1}-1}) n_{k-1} (t_k - t_{k-1})} \quad (14)$$

Differentiating with respect to  $q$  and  $\beta$  produces equivalent type equations which will allow the estimates for  $\hat{q}$  and  $\hat{\beta}$  to be determined in the same manner as follows.

Generally, the two equations (13) and (14) can now be solved simultaneously to determine the values for  $\hat{\beta}$  and  $\hat{\alpha}$ . Unfortunately, this is easier said than done. The complexity of these equations (more so in the heterogeneous case) does not allow explicit equations for  $\hat{\beta}$  and  $\hat{\alpha}$ . The remainder of this chapter will discuss a method for determining the estimates of  $p$  and  $\alpha$  from these equations and a way to extract the necessary data from a high resolution Monte Carlo simulation run to compute these estimates.





#### E. ESTIMATING PARAMETERS FROM A HIGH RESOLUTION MODEL

As mentioned before, equations (13) and (14) must be solved simultaneously to produce values for  $\hat{\alpha}$  and  $\hat{p}$ . Generally, these equations are too complicated to produce such values easily so other techniques must be used. The method suggested by Clark is to enter a value for  $\hat{p}$  in equation (14) and solve for  $\hat{\alpha}$ . This value and the selected value for  $\hat{p}$  are then put in equation (13) and the equation is evaluated. Notice that both values are estimates since we are computing the maximum likelihood estimates of  $p$  and  $\alpha$ . The values of  $\hat{p}$  and  $\hat{\alpha}$  which give a value for equation (13) closest to zero are the best maximum likelihood estimates for  $p$  and  $\alpha$ . If equation (13) equalled zero exactly, the true values of the maximum likelihood estimates would be known.

In using these equations, the input received from the high resolution, Monte Carlo simulation must include:

- the time between casualties;

- the number of RED and BLUE survivors prior to the  $k$ th casualty;

- the total number of casualties for RED and BLUE for the battle;

- the type of casualty (RED or BLUE) of the  $k$ th casualty.



In Clark's theory for a homogeneous force battle, the conditional attrition rates and the probabilities that a target is not acquired are assumed to be constant over the entire battle. This means that equations (13) and (14) are summed over all casualties in the battle and the estimates for  $p$  and  $\alpha$ , which are determined from them, are also assumed to be constant over the entire battle.

In applying this theory to STAR output, the authors obtained questionable results for the values of the parameter estimates. The estimates,  $\hat{p}$  and  $\hat{q}$ , were computed to have values of 0.99 and 0.93 respectively. These values imply that both BLUE and RED forces experienced difficulty in acquiring targets. Analysis of the Fulda Gap terrain and consideration of the respective locations of the opposing forces support the estimated values for  $p$  and  $q$ . However, the stated value for  $\hat{p}$ , 0.99, is a truncation of the actual value computed. If proper rounding procedures had been used,  $\hat{p}$  would have been set equal to 1.0, which means that the RED forces would not detect any BLUE targets. Nondetection implies that no BLUE attrition will occur. But this contradicts the STAR battle which did, in fact, produce BLUE casualties amounting to about two-thirds of the total BLUE force.



The estimates,  $\hat{\alpha}$  and  $\hat{\beta}$ , were computed to be 2.4 and 0.03, respectively. The relatively large value of  $\hat{\alpha}$  implies that when the RED forces are able to detect BLUE targets, the BLUE force will suffer heavy casualties. There appears to be an unusually large difference between the values for  $\hat{\alpha}$  and  $\hat{\beta}$  which are not reflected by the values for  $\hat{p}$  and  $\hat{q}$ . This disparity is most likely attributable to the restriction that all parameter values be held constant over the entire battle. Experimentation with different parameter values in DAMSTAC indicates that a value of about 0.40 more closely approximates the attrition observed in the STAR battle. Experience with these computations reveals that this is not necessarily the case and that a more likely assumption is that the parameters are constant over different time intervals of the battle. In general, a simple battle can be divided into phases where the intensity of the battle is constant within each phase but different among the phases. Basically, the phases are:

movement to contact (low intensity)

initial contact (mid intensity)

main battle (high intensity)

withdrawal from contact or annihilation (mid/low intensity)



Moving from one phase of the battle to the next should cause a change in conditional casualty rates ( $\alpha$  and  $\beta$ ) as well as the probability of not acquiring a target ( $p$  and  $q$ ).

The question now becomes how to determine the breakdown of the battle by phases using the output from a high resolution, Monte Carlo simulation. That is, where do the changes in phases occur in the simulation? One possible method is to look at the number of casualties as a function of time. Another is to look at the number of shots fired as a function of time (see Figure 11). In both cases, time is segmented into time intervals (eg. every 100 seconds) and a histogram of the casualties or shots is plotted for each of these intervals. Having done this for several battles, the results identify fairly clear choices for the end of one phase of the battle and the beginning of the next phase. However, more analysis of these two methods reveals that they might not truly identify the phases of the battle and that an alternate method should be considered, primarily one based on range. This concept is discussed in detail in Chapter VI.

Using the number of casualties per time interval, a distorted picture of the intensity of the battle might be obtained. The interaction of the probability of acquiring a





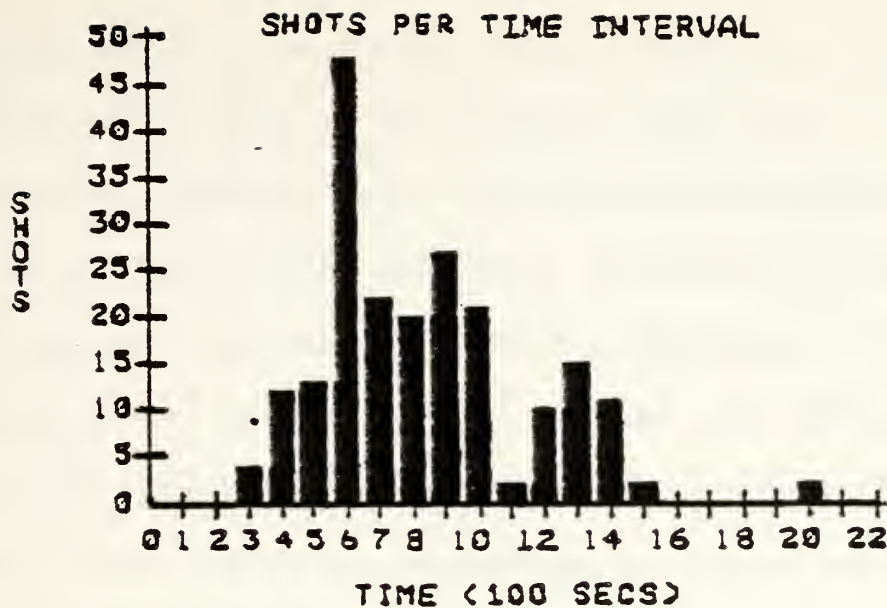


Figure 11: Histogram of Shots per Time Interval

target with the attrition rate of a firer might offset each other and produce results which conflict with the true battle intensity. In other words, if the acquisition probability is high but the attrition rate is low, the number of casualties in a time interval might indicate a low intensity phase of the battle when, in fact, it is a high intensity phase. Therefore, this method should be used with caution, if at all. The method of using the number of shots per time interval has similar faults. Twenty shots by one firer in a time interval is much different in terms of intensity than one shot by twenty firers. Again, this method should be used with caution.



The question is then: what method should be used? One method, which is used by the Combined Arms Combat Development Activity (CACDA/CASAA), is measuring the number of shots per firer per time interval.<sup>1</sup> Although it also has some faults, it does provide a better indication of the intensity of the battle. It is, for the most part, independent of the conditional casualty rates, although the number of shots would indicate a dependency on target acquisition. This dependency is reduced by averaging the number of shots over the number of firers. In effect, this measure can be considered to be unbiased by the changes in conditional casualty rates and probabilities of not acquiring targets. Thus one is able to get a feel for the intensity of the battle from the histogram of the number of shots per firer per time interval. This is not necessarily scientific reasoning, but it seems to work.

Once the phases of the battle are delineated for a high resolution, Monte Carlo simulation run, the next step is to determine how to treat the 'dead' time from the beginning of a phase to the first casualty and from the time of the last casualty to the end of the phase. For phases in the middle

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<sup>1</sup>Conversation with Mr. Ernest Boehner from CASAA on 5 December 1981



of the battle, each of these two times is a portion of the time between two casualties and should thus have a bearing on our maximum likelihood estimates from equations (13) and (14).

To resolve this situation, the time of the last casualty within a phase is used as the end of the phase. For example, if a phase is supposed to end at 1200 seconds and casualties occur at 1140 and 1225 seconds, the phase will be terminated at 1140 and the new phase begun at 1141. This also allows this time between casualties to be accounted for in the next phase. This method produces some variation in phase lengths when running several replications of the battle, but this variation is minimal, especially since the beginning and end of phases are being judged from something less than a scientific method.

Several replications, as many as affordable, should be used to compute the maximum likelihood estimates for the four parameters. By using a large sample population (the casualties), a more accurate estimate of the parameter can be obtained. Likewise, when the heterogeneous model is used, a larger sample population is desirable, since the number of engagements between two particular weapons systems will be much less than the number of engagements in the



homogeneous case. This could produce values that are statistically insignificant.

A postprocessor to the high resolution model was developed to make the numerous calculations required to produce these estimators. The postprocessor uses an optimization routine to determine the maximum likelihood estimates from the given equations. Detailed information on the postprocessor is provided in Appendix E.





#### IV. ALTERNATE FUNCTIONAL FORMS

Different military situations have been hypothesized to yield different functional forms for Lanchester-type equations. The term "Lanchester-type equations" refers to any differential-equation model of combat and the term "functional form" relates to the structure of the attrition rate, i.e., how the attrition rate equation is written and which parameters are considered explicitly in the equation. Henceforth, a standard shorthand notation will be adopted to refer to the functional forms used in homogeneous-force Lanchester-type combat models. For example, Lanchester's equations of modern warfare are expressed as  $F|F$  functional forms (or, simply  $F|F$  attrition) because they are proportional to only the number of enemy firers. Taylor [Ref. 7] provides a good explanation of this convenient shorthand notation.

Generally, the classical Lanchester functional forms for expressing the attrition rate for forces using aimed fire or area fire are too simple to be used "as is" in a detailed analytical combat model. The assumptions required for these basic equations to hold are too limiting and do not allow for all of the processes that are known to occur in combat



to be considered in the force attrition model. Some of the more common functional forms for attrition rates that have been considered and used in Lanchester-combat models are shown in Table 2.

Of special interest is the T|T functional form. This functional form is particularly useful in describing attrition in target rich environments. Peterson [Ref. 8] hypothesized that the equations,

$$dx/dt = -ax \text{ and } dy/dt = -by,$$

characterize the early stages of a small unit engagement in which the vulnerability of a force dominates its ability to acquire enemy targets. It is recommended that Peterson's T|T functional form be considered in the heterogeneous model described in Chapter VI to model attrition in the initial phase of the battle. The remaining sections of this chapter will discuss several not-so-common functional forms that have been formulated and used in "recently" developed combat models.

#### A. HELMBOLD-TYPE EQUATIONS

An alternative functional form for homogeneous-force attrition rates was proposed by R. Helmbold. Helmbold believed that when opposing force sizes were grossly unequal, the larger force experienced "inefficiencies of scale"



Table 2: FUNCTIONAL FORM NOTATION

FUNCTIONAL FORM	DIFFERENTIAL EQUATION
F F	$\frac{dx}{dt} = -ay$ $\frac{dy}{dt} = -bx$
FT FT	$\frac{dx}{dt} = -axy$ $\frac{dy}{dt} = -bxy$
F FT	$\frac{dx}{dt} = -ay$ $\frac{dy}{dt} = -bxy$
T T	$\frac{dx}{dt} = -ax$ $\frac{dy}{dt} = -by$
(F+T)   (F+T)	$\frac{dx}{dt} = -ay - cx$ $\frac{dy}{dt} = -bx + dy$

in producing casualties. Limitations on space available for maneuver, reduced reaction time, increased command, control, and communication problems, etc. result in the reduction of casualty producing effectiveness. These limitations may well prevent the larger force from using its full destructive capability against the smaller force. There is no definition for "grossly" unequal force sizes, but the following hypothesis is proposed. The validity of using Helmbold's equations in a combat model is directly related not only to the force ratios (i.e.,  $x/y$  or  $y/x$ ) but to the relative size of the two opposing forces with respect to their surrounding terrain. For example, a 5 to 1 force ratio may



well be a situation where Helmbold's equations apply if both of the opposing force sizes are relatively large with respect to the terrain available to them for movement, concealment, etc. Conversely, a force with a 30 to 1 force ratio may not exhibit inefficiencies of scale if the opposing force sizes are small in relative sizes and with respect to their surrounding terrain. Consequently the decision to use Helmbold's functional form for attrition rates rather than some other form (like Lanchester's equation for modern combat) really depends on the tactical "situation".

Helmbold's functional form introduces a modification that accounts for the reduced fire effectiveness of the larger force. In mathematical form his equations would read:

$$dx/dt = -a g(x/y) y \quad \text{with } x(0) = x_0$$

$$dy/dt = -b h(y/x) x \quad \text{with } y(0) = y_0$$

where  $a$  and  $b$  represent time-dependent attrition-rate coefficients, and  $g(x/y)$  and  $h(y/x)$  represent functions that modify fire effectiveness of individual  $x$  and  $y$  firers respectively. According to Helmbold's hypothesis the two functions  $g(x/y)$  and  $h(y/x)$  must satisfy:

$$g(1) = h(1) = 1$$

$$g(u) = h(u) = E(u)$$

$E(u)$  is a strictly increasing function of  $u$ .





So, the generalized Helmbold-type combat equations can be written as:

$$dx/dt = -a E(x/y) y$$

$$dy/dt = -b E(y/x) x$$

For the case in which  $E(u) = u^c$  with  $c$  a constant greater than or equal to zero, the following equations for Helmbold-type combat are obtained:

$$dx/dt = -a (x/y)^{1-W} y \quad \text{with } x(0) = x_0$$

$$dy/dt = -b (y/x)^{1-W} x \quad \text{with } y(0) = y_0$$

$W$  is commonly called the "Weiss parameter" with  $W = 1-c$ .

The above equations represent the special exponential case of Helmbold combat. If  $a(t)$  and  $b(t)$  represent constant attrition rate coefficients denoted by  $a$  and  $b$  respectively, then, when  $W = 1$ , the above equations reduce to Lanchester's Equations for Modern Combat. When  $W = 1/2$  Lanchester's Area-fire Equations are obtained.

## B. HOW TO CHOOSE THE RIGHT FUNCTIONAL FORM

A very logical question that readers of this study may ask at this time is, "Now that I've seen some of the Lanchester-type attrition rate functional forms, which one should I choose for my analytical model?" The answer to this question is that there is no answer to this question. The choice of functional form is purely arbitrary and is



usually left to the discretion of the model builder. The following steps, however, may help in this choice.

1. Carefully consider the scenario that the combat model is intended to portray. The scenario may well indicate that some particular subset of the functional forms is preferable.

2. List the assumptions that must be made for each of the functional forms in the subset to hold and see which assumptions are acceptable to you and your model and which are not.

3. Observe the parameters involved in each functional form and eliminate those forms for which the parameter values or estimates are unobtainable or for which you are not willing to plug in arbitrary values.

At this point, the final selection of functional form is purely one of subjective judgement.

There is no requirement, however, that a model builder must accept one of the already developed functional forms. There is no doubt that other forms can be formulated, but the formulation will require extensive research, analysis and work. A good check to see if an attrition rate equation is reasonable is to insure that the Lanchester classical equations are special cases of the new functional form.



Once the final functional form has been selected or formulated, it may be enhanced as necessary to reflect more of the complexity and realism of combat. Some additional operational factors that can be considered are:

Unit breakpoints and battle termination criteria;

Suppression;

C<sup>3</sup>;

Reinforcements or replacements.

The main assumption that allows these operational factors to be "added" to the attrition rate equation is that synergistic effects are not considered in Lanchester-type force-on-force combat models. No synergistic effects imply that the Principle of Superposition holds, therefore, the effects of the operational factors are independent and additive.



## V. FUTURE ENHANCEMENTS

There are numerous enhancements to the analytical model that can be made. The enhancements that are recommended, for the most part, are not aimed at improving the inner workings of the current model, but at building successive models that are more detailed, require fewer limiting assumptions, and are generally more complicated.

For follow-on models that retain the homogeneous force concept, it is recommended that the model have the ability to allow the user to choose alternative functional forms for the force attrition rates. This should be done to better describe the situation of the battle at a particular time. A likely method would be to change from one functional form to another during the battle in order to more realistically portray the attrition occurring then. This enhancement would require considerable effort in developing the maximum likelihood estimates for the various parameters used in each alternative functional form, additional work with the STAR postprocessor, and significant change to the current DAMSTAC model. Questions which arise from this suggestion are:

Which form(s) should be chosen?





How do you know when to change functional form?

These questions are partially answered in Section IV-C.

Further research into this area is required.

The movement subroutine of the model needs to be modified to more realistically portray the movement of units on the battlefield. Even though a relatively low-resolution time-step operation is occurring, the resolution of the movement of units can be refined to vary the rate of movement from one time step to the next, if necessary. Currently, a change in rate of movement occurs only at the initial contact between forces and at breakpoints. The rate of advance of the RED forces should be allowed to vary based on decision logic which considers attrition rate, terrain, etc. BLUE forces should be given the capability to move to alternate or fall back positions when the battle situation dictates. Decision logic must be enhanced to allow BLUE forces to move to alternate or fall-back positions. It should be noted that this "pace of battle" question has never been fully explained or understood, however, the movement routine logic in DAMSTAC should parallel that of STAR.

The concept of units having different formations is ignored in the current model. Units are identified by a



point location only. Some work needs to be done to allow the units to take on different formations for road marches, attacks, etc. In order to do this, additional attributes such as frontage, depth, orientation and geometric configuration should be considered to describe the formation of the unit. A postprocessor for STAR could take the individual tank locations from the STAR data base and determine the above mentioned attributes for input into the DAMSTAC model. Attrition rates on both sides must be adjusted for the various formations of an attacking unit.

The inclusion of indirect fire, suppression, smoke, intelligence, and close air support are all important to making the model a usable analytical tool. Additions of communications and logistics, primarily ammunition and petroleum, oil, and lubricants (POL), are also important enhancements that must be included in the model.

As was seen in Section III-E-3,  $P_{va}$ , the probability that a target is visible and acquired in the steady state is

$$P_{va} = P_a P_v = \left( \frac{\lambda}{\lambda + \mu} \right) \left( \frac{\eta}{\eta + \mu} \right) \quad (15)$$

Both of the factors represent a particular element of the attrition process, one the terrain affects on line of sight,



and the other, the acquisition process. It should be apparent that these two factors can be separated from each other with the only common variable,  $\mu$ , the rate of transfer from the visible state to the invisible state. With this factorization, if the line of sight parameters for a particular terrain type are known and the attrition rate coefficients have been determined, the target acquisition capability of a weapon system against another weapon system can be determined. This would allow the target acquisition parameter to be used for other terrain types to compute attrition rate coefficients without having to estimate the coefficients from a high resolution simulation.

The concept works in this manner. Runs are made on the high resolution model (STAR) using a particular terrain. The attrition coefficients are determined using the maximum likelihood estimates described in Section III-D. With predetermined data for the terrain coefficients, the line of sight parameter can be factored out of the attrition rate coefficient,  $A$ . This would leave the value of the acquisition factor which should theoretically be constant for the firer-target type combination used in the scenario. With this value and the terrain coefficient for other types of terrain, the attrition rate coefficient can be determined



for a new scenario with the same firer-target combination, without running the high resolution model again. This method assumes that the terrain affects and the target acquisition process are independent of each other. The impact of this concept is enormous in terms of time and cost saved from not having to make multiple runs of the high resolution model.

One concept which is not strictly an enhancement but is an important consideration is the idea of using simulated combat data from a source other than STAR. Specifically, data generated at the National Training Center from actual field exercises could conceivably be used to compute attrition coefficients in much the same manner as STAR. What this provides is not only an alternate source of data, but also a different model, since it would include many human factors that would not likely be accounted for in STAR. Depending on the intended use of the model, one source or the other may be desirable.

It is necessary that a progression from homogeneous forces to heterogeneous forces be made if DAMSTAC is ever to be really useful. This enhancement entails a significant amount of research, model building, and statistical analysis in order to implement the concept of heterogeneous forces





into the analytical model. Target priorities, fire allocation algorithms, and a library of attrition rate coefficients must be developed for various scenarios and force mixes. Changing the model to a heterogeneous type requires some changes in the equations (13) and (14), and thus some significant modifications to the postprocessor for the model.



## VI. HETEROGENEOUS MODEL

DAMSTAC, in its current configuration, models combat between two opposing homogeneous forces, but actual combat consists of many different weapon-system types operating together as combined arms teams. For example, there may be infantry, tanks, antitank weapons, artillery, etc. on each side. A necessary extension or modification, therefore, to DAMSTAC is the consideration of combat between heterogeneous forces. This chapter briefly indicates how the basic ideas and methodologies used previously to model combat attrition for homogeneous forces can be extended and adapted to the heterogeneous force structure.

A key assumption that must be made in order to model combat between heterogeneous forces, where Lanchester-type differential equations are used, is that the attrition effects of various different enemy weapon systems types against a particular friendly target type are additive. In other words, synergistic effects between weapon system types are not considered [Ref. 9]. Also inherent in the modelling of heterogeneous force combat is the need to introduce an allocation factor. This allocation factor may be defined as the fraction of the firers of a particular type that engage



a particular target type. The allocation factor concept will be discussed in greater detail later in this chapter.

One theoretical concept for modelling the attrition process between two opposing forces is to consider attrition as a nonstationary Markov process where the states of the process are defined as the numbers and types of surviving combatants and the ranges between opposing combatants. The transition probabilities between the Markov states, under this concept, depend on the ratio at which surviving combatants or weapon systems inflict casualties on a particular type of opposing combatant. Thus the nonstationary Markov process model provides a means of relating the sequence of states and the times of the state transitions observed during a battle to attrition rate coefficients. In turn, this allows for the estimation of attrition rate coefficients on the basis of the observed sequence of states and transition times. Andrighetti [Ref. 10] developed such a nonstationary Markov model that related weapon system effectiveness to the time sequence of casualties observed in a two-sided, heterogeneous force land combat simulation. There is a flaw, however, in Andrighetti's work that readers should note. He implies that his methodology is easily extended to time-dependent attrition rate coefficients. This is not true.



Andrighetti's thesis does contain a good discussion on the theoretical background which allows for the maximum likelihood estimation of parameters used in attrition rate equations. An important observation made by Andrighetti in his thesis is that the difference-differential equations obtained from the Chapman-Kolmogorov equations of the nonstationary Markov model are susceptible to a general solution only in special cases as Gordon Clark showed in his doctoral dissertation. Clark used the Chapman-Kolmogorov equations to develop expressions for time state probabilities and the expected survivors in a heterogeneous force battle.

The extended version of the DAMSTAC model which shall be called DAMSTAC II should be a heterogeneous force analytical model that uses STAR output to compute parameter values. These parameter values should be allowed to change as the distance or range between opposing forces vary during the battle. In DAMSTAC, an attempt was made to allow the parameter values to change with respect to time. However, it was discovered that the maximum likelihood estimators developed for the critical parameters in the attrition rate equations could not be used for time dependent variables. Two feasible alternatives that allowed for variable parameter values





were considered. Both alternatives are recommended for future evaluation. The first alternative looks at dividing the battle into phases based on battle intensity as measured by the number of shots divided by the number of live firers. (Refer to Section III-E) The second alternative for dividing the battle into phases is based on the range between combatants. Here also the parameters can change from phase to phase. This technique will work assuming that the combatants on each side move as a single force and that units are located by their centers of mass. For example, a battle can be divided into three distinct time intervals or phases of combat: an artillery prep phase during which all combat vehicles and weapon systems, other than artillery, are not participating; a moderate to long range battle phase; and, a terminal shorter range battle phase. Parameter values can then be computed, using procedures to be discussed later, for each battle phase. This second alternative is used in the COMANEW model and is the one recommended for DAMSTAC II.

#### A. THE ATTRITION-RATE FUNCTIONAL FORM

The attrition rate functional form that will ultimately be chosen for the heterogeneous force model is, of course, the prerogative of the modeller. The authors of this thesis, however, would like to recommend two related attrition



rate functional forms for consideration. The first, which shall be labeled as Functional Form 1 (FF1), is based on the assumption that during the course of a battle fire is directed at the highest priority target surviving and acquired. Also it is assumed that the relative priority of target weapon types, as considered by each firer, remains constant throughout the engagement and that this relative priority is identical for each firing weapon type. Functional Form 1, developed by Gordon Clark for use in the COMAN model, can be written as follows:

$$f_{bj}^{(i)}(m, n) = \sum_{k=1}^r \alpha_{ijk} n_k p_i^{m_j'} (1 - p^{m_j}) \quad (16)$$

$$f_{rk}^{(i)}(m, n) = \sum_{j=1}^b \beta_{ijk} m_j q_i^{n_k'} (1 - q^{n_k})$$

where

$f_{bj}^{(i)}(m, n)$  = conditional casualty rate of BLUE weapons of type  $j$  during phase  $i$  of the battle given strengths of  $m$  and  $n$ .

$f_{rk}^{(i)}(m, n)$  = analog of  $f_{bj}$  for RED weapons of type  $k$ .



$n_k$  = the number of surviving RED weapons of type k

$m_j$  = the number of surviving BLUE weapons of type j

$\beta_{ikj}$  = kill rate of a BLUE firer of type j for an acquired RED target of type k in the i'th time interval.

$\alpha_{ijk}$  = kill rate for a red-firer/blue-target combination corresponding to  $\beta_{ikj}$

$q_i$  = the probability that a specific RED weapon is unacquired by an individual BLUE firer in the i'th phase of the battle.

$p_i$  = the probability for a specified blue-target/red-firer combination corresponding to  $q_i$ .

$m'_j$  = the number of surviving BLUE weapons of higher priority than a type j weapon.



$n'_k$  = the number of surviving RED weapons of higher priority than a type k weapon.

The reader should note that since the assumption is made that a firer will engage the highest priority target he can acquire, the probability of a BLUE firer engaging a RED weapon of type k is  $q_i^{n'_k}(1-q_i^{n_k})$ . Similarly, the probability of a RED firer engaging a BLUE weapon of type j is  $p_j^{m'_i}(1-p_j^{m_i})$ . These two probabilities may be regarded as the allocation factors for Functional Form 1.

All of the critical parameters necessary to compute the conditional casualty rates,  $f_{b_i}^{u_i}(m,n)$  and  $f_{r_k}^{v_k}(m,n)$ , can be obtained either directly or indirectly (using maximum likelihood procedures) from the output of a high resolution simulation such as STAR.

If one is not willing to assume that target priorities remain constant throughout the battle then FF1 will not be sufficient. The terms in Clark's functional form which result from the assumption of constant target priorities are  $q_i^{n'_k}$  and  $p_j^{m'_i}$  where  $q_i^{n'_k}$  is the probability that all surviving RED weapons of higher priority than type k have not been acquired and  $p_j^{m'_i}$  is the corresponding probability for type j blue weapons.





One way to extend Clark's formulation in order that the fixed priority may be dynamically overridden is by replacing the terms  $q_i^{n_k}$  with  $\theta_{jk}$  where  $\theta_{jk}$  is defined as the probability that BLUE weapon type  $j$  engages RED weapon type  $k$ , given that BLUE weapon type  $j$  acquires at least one RED weapon type  $k$ . Note that

$$\theta_{jk}(1-q_i^{n_k}) = P(j \text{ engages } k | \text{at least one } k \text{ acquisition})$$

$$P(\text{acquire at least one } k) = P(j \text{ engages } k)$$

Functional Form 2 (FF2) may be written as;

$$f_{b_j}^{\dot{m}}(m, n) = \sum_{k=1}^r \alpha_{ijk} n_k \delta_{kj} (1-p_i^{m_j}) \quad (17)$$

$$f_{rk}^{\dot{m}}(m, n) = \sum_{j=1}^b \beta_{ikj} m_j \theta_{jk} (1-q_i^{n_k}) \quad (18)$$

where  $\delta_{kj}$  is the RED firer BLUE target probability corresponding to  $\theta_{jk}$  and all other parameters are as defined for FF1. Just as  $p, q, \alpha, \beta$  are assumed constant over the entire phase of the battle,  $\delta$  and  $\theta$ , for each  $j$  and  $k$ , are also assumed constant over the entire interval.



Serious consideration should be given to incorporating FF2 or some similar functional form into DAMSTAC II because STAR does allow target priorities to change during a battle. Target priorities in STAR are based on the types of targets on the firer's detected list and the type of ammunition the firer has available for use.

It may also be useful to use a different functional form during the initial phase of combat where attrition rates are more a function of the exposure or vulnerability of targets than they are a function of the firer's capability to acquire targets. Clark recommended the use of Peterson's Logarithmic Law to model attrition during the initial phase of the battle. [Ref. 11]

#### B. MAXIMUM LIKELIHOOD ESTIMATORS

The ability of the DAMSTAC II model to provide insight into the interactions represented in the STAR simulation is based on the estimation of conditional casualty rates ( $\alpha$  and  $\beta$ ) and other parameters from STAR data. These estimated parameters should be constant within a phase of the battle, but independent and unrelated to results in neighboring time intervals. The independence of parameter values between time intervals implies that the estimators for a specific time interval, or phase of the battle, can be defined by



analyzing a sample of data from the high resolution simulation observed during that single-time interval.

The maximum likelihood estimators (MLE's) for the unknown parameters  $\alpha, \beta, p$  and  $q$  used in FF1 were developed by Gordon Clark. It may be of interest to the reader to note that simplified versions of these MLE's were used in the DAMSTAC model for homogeneous forces, however, since we are now concerned with heterogeneous forces, the "unbridged" versions are presented. The maximum likelihood estimate for  $\alpha$  as a function of  $p$  is:

$$\hat{\alpha}_{kj}(p) = \begin{cases} \frac{B_{kj}}{\sum_{y=1}^{Y+1} n_{yk} p^{m'_{yj}} (1 - p^{m_{yj}})(t_y - t_{y-1})} & \text{for } B_{kj} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (19)$$

where  $\hat{\alpha}_{kj}(p)$  = the estimator for the parameter  $\alpha$  for a given  $p$ .

The MLE for  $p$  is found by solving:

$$\frac{\partial \ln L(p)}{\partial p} = \sum_{y=1}^{Y+1} \frac{(1 - C_y)(m'_{ygy} - (m'_{ygy} + m_{ygy})p^{m_{ygy}})}{p(1 - p^{m_{ygy}})} - \sum_{y=1}^{Y+1} \sum_{j=1}^b \sum_{k=1}^r (\hat{\alpha}_{jkl}(p) n_{yk} p^{m'_{yj}} - 1 (t_y - t_{y-1}) \cdot (m'_{yj} - (m'_{yj} + m_{yj})p^{m_{yj}})) = 0 \quad (20)$$

The equations for  $\hat{\beta}_{kj}(q)$  and  $\hat{q}$  are similar.

The estimators obtained from the above equations result from the data from a single replication of the combat simulation. More precise estimates are obtainable by using a larger sample consisting of a number of observations during



the interval in question from a number of independent replications of the STAR simulation. This modification entails an additional summation ( $\sum_x$ , where  $x$  = the total number of replications) in each of the estimating equations.

The data needed for the computations of the MLE's include;

$y$  = total number of casualties

$t_y$  = elapsed time since the beginning of the interval until the  $y$ 'th casualty

$t_{y+1}$  = the end of the battle phase or the elapsed time since the beginning of the phase until the battle ended if it is less.

$m_{yj}$  = the number of BLUE survivors of type  $j$  just prior to the  $y$ 'th casualty

$n_{yk}$  = the number of RED survivors of type  $k$  in the battle just prior to the  $y$ 'th casualty

$C_y = 1$  if the  $y$ 'th casualty is BLUE ; 0 otherwise

$f_y$  = firer weapon type for the  $y$ 'th casualty

$g_y$  = target weapon type for the  $y$ 'th casualty

$m'_{yj}$  = the number of BLUE survivors of higher priority than type  $j$  just prior to the  $y$ 'th casualty

$$m'_{yj} = \sum_{u=1}^b M_{yu}$$

$n'_{yk}$  = RED analog of  $m'_{yj}$





$B_{kj}$  = the number of BLUE weapon-type  $j$  casualties due to RED weapons of type  $k$

One technique of computing the MLE's for  $\hat{\alpha}$  and  $\hat{p}$  is to numerically determine  $\hat{p}$  using equation (20) and then substitute this value into equation (19) for  $j = 1, 2, \dots, b$  and for  $k = 1, 2, \dots, r$  ( $b$  = the total number of BLUE weapon types and  $r$  = the total number of RED weapon types). A recommended technique for numerically solving for  $\hat{p}$ , the estimate for  $p$ , can be found in Clark's work on the Dyntacs combat model [Ref. 12]. This technique is similar to the one developed for the homogeneous case discussed in Chapter III. Basically the procedure is as follows. Since  $p$  represents a probability, it must satisfy the inequality  $0 \leq p \leq 1$ . Therefore, the function  $\frac{\partial}{\partial p} \ln L(p)$  can be evaluated at points in the interval  $0 \leq p \leq 1$  until two points,  $p_1$  and  $p_2$ , are found such that the product of  $\frac{\partial}{\partial p} \ln L(p_1)$  and  $\frac{\partial}{\partial p} \ln L(p_2)$  is less than or equal to zero. Since  $\frac{\partial}{\partial p} \ln L(p)$  is a continuous function,  $\frac{\partial}{\partial p} \ln L(p) = 0$  for some  $p$  satisfying  $p_1 \leq p \leq p_2$ . This interval is reduced by evaluating  $\frac{\partial}{\partial p} \ln L(p)$  at the midpoint of the interval  $(p_1, p_2)$ . Repeating this process converges to a solution for  $\frac{\partial}{\partial p} \ln L(p)$  and this solution is a local maximum. This technique is similar to the bisection method for solving nonlinear problems.



With respect to Functional Form 2, the introduction of the  $\Theta_{jk}$  allocation terms adds considerable complexity to the maximization of the likelihood function. One way to circumvent this problem is to compute a "best guess" for the  $\Theta_{jk}$ 's from STAR samples (for the given interval). This best guess can then be substituted into the  $\Theta_{jk}$ 's prior to maximization of the likelihood function, thereby reducing the  $\Theta_{jk}$ 's to constants. The maximization can then be performed, as in Clark's original equations, with respect to  $p, q, \alpha, \beta$ .

### C. THE MODEL

The computational procedures that will constitute DAMSTAC II must be developed by the modeller who chooses to carry on the work initiated in this thesis. As a starting point, however, the techniques used by Clark in his COMAN model would be excellent choices. The adequacy of Clark's procedures in DAMSTAC II given a particular scenario and force mix, to predict attrition in a STAR simulation with the same scenario and force mix is questionable and would have to be tested. Detailed comparisons and analysis of the output from both models will be required to answer the question of model comparability and modifications to the computer code and/or computational procedures in DAMSTAC II must be accomplished as necessary. The computational cycle



employed in COMAN is based on the assumption that the distribution times between casualties in the high resolution simulation is exponentially distributed. It uses Monte Carlo procedures to generate the time until the next casualty and also to find the casualty weapon type.

The following steps constitute the computational cycle recommended for DAMSTAC II.

Step 1. The first step in the cycle sets the time equal to zero and sets the battle phase, designated by the letter  $i$ , equal to 1.

Step 2. Next the total conditional casualty rate,  $\lambda^i(m,n)$  is computed from the equation

$$\lambda^i(m,n) = \sum_{j=1}^b f_{bj}^i(m,n) + \sum_{k=1}^r f_{rk}^i(m,n) \quad \text{for } i=1,2,\dots, I \quad (21)$$

where  $f_{bj}^i(m,n)$  and  $f_{rk}^i(m,n)$  are the conditional casualty rates in phase  $i$  of the battle, given force strength  $m$  and  $n$ , for BLUE weapon type  $j$  and RED weapon type  $k$ , respectively.  $\lambda^i(m,n)$  is the parameter of the exponential distribution describing the times to the next casualty.

Step 3. Now, using the exponential distribution with parameter  $\lambda^i(m,n)$ , one Monte Carlo's for the time interval to the next casualty. Designate this time interval as  $t'$ . If the next casualty occurs in another time interval, ie. if  $t + t' > t_i$  where  $t_i$  represents the end of the  $i$ 'th battle



phase, then  $i$  is increased by 1, the time is set equal to  $t$  and the program is directed back to step 2 where  $\lambda^{i+1}(m,n)$  is selected as the distribution parameter. If, however,  $t + t' < t$ ; then the next step is to Monte Carlo for the casualty weapon type.

Step 4. The weapon type for the next casualty is represented by the random variables  $C_b$  and  $C_r$  which are defined as

$C_b = j$  if the casualty weapon is BLUE weapon type  $j$

0 if the casualty is RED

$C_r = k$  if the casualty weapon is RED weapon type  $k$

0 if the casualty is BLUE

The Monte Carlo procedure uses the conditional casualty weapon probability distributions for  $C_b$  and  $C_r$ . These probabilities are computed by

$$p^i(C_b = j | C = 1, m, n) = f_{bj}^{(i)}(m, n) / \lambda(m, n)$$

$$p^i(C_r = k | C = 1, m, n) = f_{rk}^{(i)}(m, n) / \lambda(m, n)$$

for  $i = 1, 2, \dots, I$  and when variable  $C$  is set equal to 1 if a casualty is determined to occur in interval  $i$  from the previous steps. The probability that the casualty is of a particular type is computed for each RED and BLUE type weapon. The sum of these probabilities should equal 1.







Step 5. The next step is to Monte Carlo using the Uniform  $(0,1)$  distribution to determine the casualty type. An example may help in understanding the above procedure. Suppose there are two types of BLUE weapons and two types of RED weapons. Assume the conditional casualty probabilities for each weapon are computed using the equations shown previously and they are 0.25 for each weapon type,  $b_1$ ,  $b_2$ ,  $r_1$ ,  $r_2$ . If one orders the weapon types in some arbitrary fashion such as  $b_1$ ,  $r_1$ ,  $b_2$ ,  $r_2$ , and then accumulates the probabilities on the interval  $(0,1)$ , one can assign an interval to each weapon type. The example would yield the following intervals:

$b_1 - (0, 0.25) ;$

$r_1 - (0.26, 0.50) ;$

$b_2 - (0.51, 0.75) ;$

$r_2 - (0.76, 1.00) .$

The uniform random number can then specify the casualty weapon type. If the random number is 0.60 then the casualty weapon type in our example is  $b_2$ .

Step 6. After the casualty weapon type has been found the next step is to decrement the number of that type weapon by 1. Now increase the value of  $t$  by  $t'$ , the time to the next casualty. If  $t$  is greater than or equal to  $t_1$  which



represents the ending time of the last phase of the battle, or if either side is annihilated , the battle has ended and the program terminates. If  $t$  is less than  $t_1$  then go to step 2.

Observe that the above computational procedures are stochastic in nature and different replications of an engagement will likely yield similar but different results. If this method is chosen for DAMSTAC II, variance reducing replications for each engagement should be performed.

#### D. THE STAR POSTPROCESSOR

It is very important that anyone who attempts to develop the DAMSTAC II model understand and be able to manipulate the STAR simulation model. In the initial attempts to extract data from STAR, certain subroutines must be turned off. These routines include the Smoke, Engineer, Close-air support, etc. whose effects on parameter estimates used in DAMSTAC II have not been thoroughly analyzed. The number of types of combatants played in the simulation will have to be regulated so that they do not overpower the capabilities of the analytical model. It is recommended that no more than three different types of weapon systems for each opposing force be attempted when initially formulating the heterogeneous force model.



It is important that the finished version of the analytical model be as simple and transparent as possible and not encumbered with parameter estimating algorithms and computations. This consideration plus the amount of data that must be extracted from the STAR output require the development of a STAR postprocessor program. As an illustration, if one considers a simple battle divided into three battle phases with only three types of weapon systems on each side, the DAMSTAC II model, as it has been described, requires the estimation of 114 parameter values and the computation of six attrition rates.

The postprocessor at Appendix E, developed for the homogeneous model, should provide a good foundation for the more complicated postprocessor needed for DAMSTAC II.



## VII. CONCLUDING REMARKS

The concept of using differential equations to represent combat began with Lanchester's classical equations and has developed into a very dynamic field of study. The theoretical background of the fitted parameter method has been well documented by Clark and Taylor. However, the practical application of the theory lacks this same degree of discussion and documentation. This paper has focussed on some of the techniques of applying Clark's theory to an actual high resolution, Monte Carlo simulation. The problems are real and, as has been seen, the solutions presented are not doctrine. It is hoped that further investigation, elaboration and documentation of this modelling technique will occur in the near future.

The choice of which functional form to use in a particular analytical combat model is entirely up to the discretion of the model builder. In choosing an attrition rate functional form the model builder should consider the scenario portrayed in the model and the assumptions that are compatible with it.

Finally, it is recommended that the entire program for the model be converted to the UCSD Pascal language on the





Apple II. The basic structure of Pascal is more conducive to combat modelling simulation than the structure of the BASIC language. The concept of entities and attributes found in SIMSCRIPT II.5 can be closely emulated in Pascal while this is not as easily accomplished or clearly defined in BASIC.

The modular structure of procedures and functions in Pascal is also an advantage in the enhancement process of model building. Modellers can use one procedure to represent a particular action or phenomenon occurring on the battlefield. Any action which is unable to be modelled can be left in the program as a dummy procedure for later work.

Additionally, the Pascal language allows more descriptive variables to be used than the two-character variables used in Applesoft. This would make the program itself more transparent and easier to modify and update.

The DAMSTAC model is clearly in its infancy stage. Through continued enhancement, this model can contribute to the ongoing work in the field of combat analysis.



## APPENDIX A

### LIST OF VARIABLES

A = casualty rate for RED attritting acquired BLUE targets

AN = angle in radians measured counter-clockwise from due east made by the line between the current unit location and the next coordinating point.

B = casualty rate for BLUE attritting acquired RED targets

BE = the breakpoint for the BLUE force

BM = movement criteria for BLUE units as a fraction of unit strength

BF(I) = number of RED targets being fired at by BLUE unit I

BP(I) = most recently passed coordinating point for BLUE unit I

BR(I) = rate of movement for BLUE unit I in M/SEC

BT(I,J) = attrition(casualties) caused by RED unit J on BLUE unit I in one on one battle

BX(I,J) = x-coord of coordinating point J for BLUE unit I

BY(I,J) = y-coord of coordinating point J for BLUE unit I

B0(I) = current total BLUE force strength for time period I

B0(0) = initial BLUE force strength

B1 = number of coordinating points for BLUE (including



initial location)

B1(I) = initial strength of BLUE unit I

DB(I) = number of casualties or amount of attrition for  
BLUE unit I

DH = distance travelled by a unit in time increment DT, at  
speed RT

DI = distance between current unit location and next turn  
point

DR(J) = number of casualties or amount of attrition for RED  
unit J

DT = time increment

DX = x component of distance between current unit location  
and next coordinating point

DY = y component of distance between current unit location  
and next coordinating point

D1 = x component of distance moved in time increment DT, at  
speed RR(I) or BR(I)

D2 = y component of distance moved in time increment DT, at  
speed RR(I) or BR(I)

M = number of BLUE units

MT = max time of simulation

N = number of RED units

N\$ = file name (used recursively)



P = probability that a BLUE target is not acquired by  
a RED unit

PI = 3.141592654

PR = status of printer; 0 = printer is off  
1 = printer is on

Q = probability that a RED target is not acquired by  
a BLUE unit

RE = the breakpoint for the RED force

RF(J) = number of BLUE targets being fired at by RED unit J

RG = range between a BLUE unit and a RED unit

RM = movement criteria for RED units as a fraction of  
unit strength

RP(I) = most recently passed coordinating point for RED  
unit I

RR(I) = rate of movement for RED unit I in M/SEC

RT(J,I) = attrition (casualties) caused by BLUE unit I on  
RED unit J in one on one battle

RX(I,J) = x-coord of coordinating point J for RED unit I

RY(I,J) = y-coord of coordinating point J for RED unit I

R0(I) = current total RED force strength for time period I

R0(0) = initial total RED force strength

R1 = number of coordinating points for RED (including  
initial location)





R1(I) = initial strength of RED unit I

SB(I) = size of BLUE unit I

SR(I) = size of RED unit I

T = simulation time

XB(I) = current x-coord for BLUE unit I

XR(I) = current x-coord for RED unit I

YB(I) = current y-coord for BLUE unit I

YR(I) = current y-coord for RED unit I



## APPENDIX B

### NOTES ON THE COMPUTER MODEL

1. Data which have been hardwired into the model are:

A = 2.4

B = 0.03

BE = 0.3

BT = 0

DT = 30

MT = 1500

P = 0.99

PI = 3.141592654

Q = 0.93

RE = 0.3

2. Once contact is made (range  $\leq 2700$ ), the rate of advance decreases to 2 meters/second.

3. The option exists within the program to allow the movement of units based on a criteria of fractional force strength. When unit strength goes to 50% (movement criteria), the unit will move to an alternate location (for BLUE units) or retreat along its path of advance (for RED units).



## APPENDIX C

### UTILITY PROGRAMS

This appendix provides a brief description of the utility programs associated with the Aggregated Model of STAR on the Apple II Computer. These programs provide the capability to the user to transfer the necessary data from the STAR model to this model with the minimum effort.

The utility programs available are:

Force Maker

Results Reader

Both programs are interactive with the user, who answers questions provided by the computer. These programs use the commands for the Apple II Disk Operating System (DOS) which allow them to read/write Sequential Text Files and Random Access Files onto the disk. Familiarity with these types of files and the DOS would improve the understanding of these utility programs. [Ref. 13]

In the following program descriptions, the variable name used in the program is listed in parentheses after its description.



## A. FORCE MAKER PROGRAM

This program will write data files containing information about the two oppcsing forces.

Force Maker produces a Sequential Text File containing:

Force size (number of units) (M)

The strength of each unit (SB(I))

The number of coordinating points for movement of each unit (the first coordinating point is always the initial location of the unit) (B1(I))

The grid coordinates of each coordinating point for each unit (BX(I,J) , BY(I,J) )

The user has the option to make a file for the BLUE force or the RED force. After all the data has been entered, a data check routine will print the information for all units, so that a check for errors can be made. After the user has checked the data and identified the name for the file, the program will record the file on the diskette.

A copy of the program is included as Listing B in Appendix F and a sample session using this program is attached as Figure 12.





```

IRON FORCE MAKER
MENU:
1 MAKE FILE FOR BLUE FORCES
2 MAKE FILE FOR RED FORCES
0 QUIT

WHICH? 1
WHAT IS THE FORCE SIZE OF BLUE 3

FOR UNIT 1
HOW MANY COORDINATING POINTS (INCLUDING START LOCATION)? 1

ENTER GRID COORDS FOR COORDINATING POINT # 1
X-COORD IS 54163
Y-COORD IS 100655

FOR UNIT 2
HOW MANY COORDINATING POINTS (INCLUDING START LOCATION)? 1

ENTER GRID COORDS FOR COORDINATING POINT # 1
X-COORD IS 54788
Y-COORD IS 98120

FOR UNIT 3
HOW MANY COORDINATING POINTS (INCLUDING START LOCATION)? 1

ENTER GRID COORDS FOR COORDINATING POINT # 1
X-COORD IS 57148
Y-COORD IS 97893

*** DATA CHECK ***

UNIT PT X-COORD Y-COORD
1 1 54163 100655
2 1 54788 98120
3 1 57148 97893
ANY CHANGES? (Y/N) N
NAME OF FILE? THESIS
MENU:
1 MAKE FILE FOR BLUE FORCES
2 MAKE FILE FOR RED FORCES
0 QUIT

WHICH? 0

```

Figure 12: Sample Session of Force Maker Program



## B. RESULTS READER PROGRAM

This program reads the data file of time intervals and corresponding BLUE and RED force levels produced by the model. Results Reader produces two sequential text files: the first file with suffix ".COEFS" contains:

Conditional Casualty rate,  $\alpha$  (A)

Conditional Casualty rate,  $\beta$  (B)

Probability that a BLUE target is not acquired by a RED firer (P)

Probability that a RED target is not acquired by a BLUE firer (Q)

The second file with suffix ".RESULTS" contains:

The number of data points for BLUE force level versus time (N)

The number of data points for RED force level versus time (N)

Time of the battle at time interval I (T)

BLUE force level corresponding to time interval I ( $B_0(I)$ )

Time of the battle at time interval I (T)

RED force level corresponding to time interval I ( $R_0(I)$ )

The ".RESULTS" file contains some duplication of data for the following reasons. With the ".RESULTS" file written in this format, and free of additional data such as that in the



".COEFS" file, it can be used directly by the Apple Plot Program to produce a plot of the force levels versus time. A listing of the program is included as Listing C in Appendix F. A sample plot of the DAMSTAC output data produced by the Apple Plot Program is included as Figure 13. A sample of the output of DAMSTAC from Results Reader is included as Figure 14.

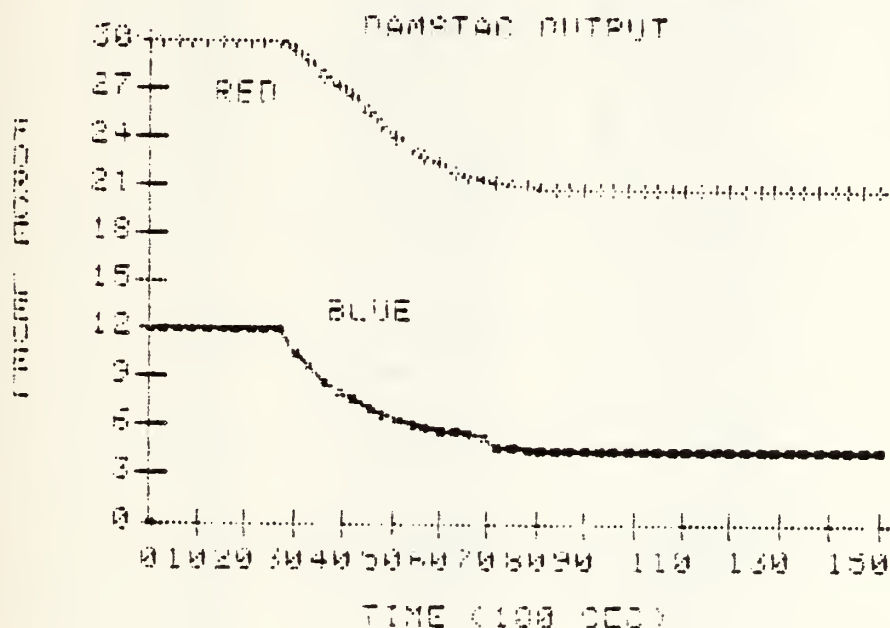


Figure 13: Sample Plot of Results Reader Program Output



1 = 1.0  
 2 = 1.0  
 3 = 1.0  
 4 = 1.0

TIME	BLUE	RED
0	12	30
30	12	30
60	12	30
90	12	30
120	12	30
150	12	30
180	12	30
210	12	30
240	12	30
270	12	30
300	10.5026484	29.2156531
330	9.59579136	28.7382045
360	8.56389142	27.6546938
390	8.00097463	27.052176
420	7.56472333	26.577368
450	7.08704096	26.3177348
480	6.70280572	24.6362284
510	6.38847607	23.8943327
540	6.12759523	23.2637501
570	5.9097524	22.7232327
600	5.72306856	22.2565234
630	5.5642176	21.8509775
660	5.38920891	21.5240217
690	5.23620713	21.424205
720	4.69145474	21.1161326
750	4.59005959	20.9828377
780	4.42658501	20.8620826
810	4.4156453	20.7521797
840	4.4156453	20.7521797
870	4.4156453	20.7521797
900	4.4156453	20.7521797
930	4.4156453	20.7521797
960	4.4156453	20.7521797
990	4.4156453	20.7521797
1020	4.4156453	20.7521797
1050	4.4156453	20.7521797
1080	4.4156453	20.7521797
1110	4.4156453	20.7521797
1140	4.4156453	20.7521797
1170	4.4156453	20.7521797
1200	4.4156453	20.7521797

Figure 14: Sample Output from Results Reader Program





## APPENDIX D

### THE TERRAIN MODEL

In addition to the basic computer model, work was done to input the STAR terrain data base into the Apple II computer. This effort was done during the initial phase of the thesis work based on an erroneous assumption that the authors made concerning the functional form of the attrition rates. This assumption was that the terrain of the battlefield and line of sight computations must be explicitly played in the model. In the given functional forms for the attrition rates, line of sight and terrain are accounted for by the probability values of  $p$  and  $q$ .

Before this assumption was found to be false, four utility programs, and a model that computed the elevations of the units were developed and are included in this document for possible future use. If further work is done with a model on the Apple II computer, the ability to input the STAR terrain into the Apple II may become an important part of the model. Examples of models that might use the STAR terrain in the Apple II are small aggregated models with functional forms that explicitly play line of sight, or



small, high-resolution models that are suitable on the Apple II computer.

#### A. THE TERRAIN UTILITY PROGRAMS

The utility programs that allow the STAR terrain to be input in the Apple II computer are listed below.

Map Maker

Hill Maker

Woods Maker

Forest Maker

These four programs have two portions each: a file maker and a file reader. In general, the file maker portion allows the user to input a new file or update/change an old file. The file reader allows the user to print out on the screen or to a printer the selected file.

For the Apple II combat model, a STAR terrain file (eg. FULTERR file) is divided into its four main parts:

the list of hill reference numbers in each grid square;

the hill parameters;

the list of forest reference numbers in each grid square;

the forest ellipse fitting parameters.

Each part is created, respectively, by one of the four utility programs: Map Maker, Hill Maker, Woods Maker, and Forest



Maker. When these parts are being created on the Apple Disk, the same general file name must be used to identify the data's terrain (eg. FULDA). Each of the utility programs will add its own suffix to the general file name. For example, for the Fulda terrain, the four utility programs will produce files named:

FULDA.MAP

FULDA.HILLS

FULDA.WOODS

FULDA.FORESTS

This suffix identifies the file as a particular portion of the terrain data, and will allow the Apple computer to recognize it from the other files with the same terrain name when reading the file for the combat model.

#### 1. Map Maker Program

This program will read and write data files containing a catalog by grid square of the hills which influence the terrain in that grid square. This program produces an equivalent file to that in STAR called LIST.H. Map Maker produces a Sequential Text File containing:

The size of the battlefield (normally 10 by 10) (L,W)

The lower left grid square in 1000 meter units (LX,LY)

The base elevation of the battlefield (HL(0,0,0))



For each grid square I,J:

(1) The number of hills influencing the terrain

(HL(I,J,0))

(2) The reference number of these hills (HL(I,J,K))

The user has the option to make a new file or access an old file for updating or changes. For new files, the program will start with the lower left grid square and proceed from west to east then south to north. The data can be saved after the information for a grid square has been entered. For old files, the program will access it, print out the file on the screen and ask for the starting grid square. The grid square index is used to identify in which grid square to start. The grid square index is an integer from 1 to L in the east-west direction, and 1 to W in the south-north direction of an L by W sized battlefield. The lower left grid square is 1,1; the lower right is L,1; the upper left is 1,W; and the upper right is L,W.

A copy of the program is attached as Listing D in Appendix F and a sample file is attached as Figure 15.





APR#0NAME OF MAP: FULDA  
 LOWER LEFT GRID SQUARE: 50 93  
 SIZE OF MAP: 10 BY 10  
 BASE ELEVATION: 300

1	1	3
22 25 26		
1	2	3
26 25 125		
1	3	5
79 126 80 111 26		
1	4	6
127 78 36 128 111 130		
1	5	5
37 128 130 36 38		
1	5	3
128 74 131		
1	7	7
74 122 115 116 114 132 44		
1	8	5
116 115 120 121 122		
1	9	6
115 144 10 116 118 53		
1	10	4
54 9 144 115		
2	1	3
22 27 26		
2	2	5
25 27 26 126 112 111		
2	3	4
111 126 112 25		
2	4	7
79 111 36 37 134 127 128		
2	5	7
36 37 75 128 134 74 72		
2	6	7
74 114 72 73 128 75 76		
2	7	5
44 114 143 115 74		
2	8	7
122 142 91 115 123 121 44		
2	9	7
119 123 122 119 144 115 142		
2	10	4
108 118 54 144		

Figure 15: Sample File for Map Maker Program



## 2. Hill Maker Program

This program reads/writes data files containing the fitting parameters for each hill on the battlefield. Hill Maker produces a Random Access Text File containing:

The number of hills on the battlefield (N)

For each hill I:

(1) X coord of the center location of the hill (H(I,1))

(2) Y coord of the center location of the hill (H(I,1))

(3) The elevation of the hill top measured from zero=sea level (H(I,3))

(4) The orientation angle of the ellipse measured in degrees counter-clockwise from east to the major axis.  
(H(I,4))

(5) The eccentricity, defined as the ratio of major axis length to minor axis length (H(I,5))

(6) The spread, defined as the distance in meters measured along the major axis from hill center to the contour line which is 50 meters down from the peak (H(I,6))

(7) The maximum height of the normal curve describing this hill mass (H(I,7))

(8) The vertical distance measured from the peak beyond which this hill is not considered in computations (H(I,8))



A copy of the program is included as Listing E in Appendix F, and a sample file is attached as Figure 16.

### 3. Woods Maker Program

This program will read and write data files containing a catalog by grid square of the woods which influence the terrain in that grid square. This program produces an equivalent file to that of Map Maker. Woods Maker produces a Sequential Text File containing:

The size of the battlefield (normally 10 by 10) (L,W)

The lower left grid square in 1000 meter units (LX,LX)

For each grid square I,J:

(1) The number of forests influencing the terrain

(FL(I,J,0))

(2) The reference number of these forests (FL(I,J,K))

Woods Maker contains the same options as those found in Map Maker. A copy of the program is attached as Listing F in Appendix F, and a sample file is attached as Figure 17.

### 4. Forest Maker Program

This program reads/writes data files containing the fitting parameters for each forest on the battlefield. Forest Maker produces a Random Access Text File containing:

The number of forests on the battlefield (N)

For each forest I:



\*RUPR#0  
FULDA HILL DATA

NUMBER OF HILLS: 159

1	533	950	425	143	2	1250	250	85.75
2	540	959	430	114	3	300	250	76.85
3	540	950	430	45	2	500	250	61.11
4	542	953	430	74	2	900	180	106.16
5	544	954	435	135	2	500	250	87.58
6	549	948	450	0	1	500	300	106.18
7	559	946	460	0	1	300	350	45.53
8	563	939	450	263	3	900	500	120.54
9	505	1025	471	48	2	300	400	122.71
10	505	1014	390	48	1	300	140	30.55
11	573	960	460	40	3	900	210	95.71
12	544	1022	350	25	2	400	300	59.02
13	532	1023	325	62	3	1500	300	34.76
14	570	1019	415	130	2	1000	170	78.11
15	583	1025	390	14	2	800	250	88.93
16	595	1013	475	117	2	900	225	184.88
17	560	1009	390	4	2	1300	300	99.34
18	594	1002	460	137	1	500	225	61.75
19	573	1003	385	126	1	500	150	42.87
20	584	997	435	25	1	350	185	56.48
21	532	984	490	1	1	500	240	132.3
22	520	930	355	165	4	2000	140	64.94
23	581	1000	394	140	2	1750	100	59.91
24	584	1005	394	145	4	1000	100	42.71
25	524	949	380	200	4	2000	140	89.86
26	508	943	340	165	3	2000	100	49.92
27	530	945	390	27	2	1300	140	93.12
28	545	980	390	350	2	1000	150	63.15
29	545	984	390	89	4	1000	150	60.68
30	545	990	364	0	1	1000	100	37.97
31	561	981	400	210	2	1000	150	71.41
32	590	953	390	125	3	500	400	169.51
33	590	953	360	85	3	400	310	130.12
34	596	959	305	85	3	1500	300	196.2
35	596	959	305	120	2	1500	300	185.93
36	511	973	370	0	1	500	300	73.31
37	511	973	370	340	2	750	120	79.55
38	509	975	340	120	3	500	90	25.72
39	572	973	470	290	2	500	230	64.02
40	577	975	470	345	2	500	230	70.6

Figure 16: Sample File for Hill Maker Program





(1) X coord of the center location of the forest

(F(I,1))

(2) Y coord of the center location of the forest

(F(I,1))

(3) The height of the trees in the forest (F(I,3))

(4) The orientation angle of the ellipse describing the forest measured in degrees counter-clockwise from east to the major axis (F(I,4))

(5) The length of the semi-major axis of the ellipse

(F(I,5))

(6) The length of the semi-minor axis of the ellipse

(F(I,6))

Forest Maker contains the same options as those found in Hill Maker. A copy of the program is included as Listing G in Appendix F, and a sample file is attached as Figure 18.

## B. THE TERRAIN MODEL PROGRAM

A copy of the model which explicitly plays terrain is included in Appendix F as Listing H. A line drawn along the edge of the program delineates the terrain model portion which was added to the basic model. The additional variables required to run the terrain model are also included at



NAME OF MAP: FULDA  
 LOWER LEFT GRID SQUARE: 50 93  
 SIZE OF MAP: 10 BY 10

1	1	1
39		
1	2	1
59		
1	3	1
23		
1	4	2
23 53		
1	5	4
55 52 50 53		
1	6	3
53 97 50		
1	7	2
36 97		
1	8	2
34 96		
1	9	1
34		
1	10	3
17 95 94		
2	1	1
58		
2	2	2
3 50		
2	3	2
3 23		
2	4	2
23 53		
2	5	5
3 26 55 53 50		
2	6	3
55 97 50		
2	7	5
34 36 98 39 97		
2	8	4
35 94 98 96		
2	9	1
34		
2	10	2
17 94		
3	1	2

Figure 17: Sample File from Woods Maker Program



the end of this appendix. Professor James K. Hartman [Ref. 14] provides the details of the methodology for line of sight and elevation using the STAR terrain.

equivalent STAR variables are in ( )

A1 = computing parameter for a hill (A)

B1 = computing parameter for a hill (B)

CR = critical value parameter for a hill (CRIT.H)

C1 = conversion of orientation angle to radians

C2 = (spread of a hill)squared

FI = value of the elevation of a point due to a hill (FI)

H(I,J) = the J-th parameter for hill I; the parameters are:

1 = x-coord of the center of the hill (XC.H)

2 = y-coord of the center of the hill (YC.H)

3 = peak elevation of the hill (PEAK.H)

4 = orientation angle of the hill (ANG.H)

5 = eccentricity of the hill (ECC.H)

6 = spread of the hill (SPRD.H)

7 = max height of the hill (HT.H)

8 = cut height of the hill (CUT.H)

H(I,0) = status of hill I;

0 = hill I has not been checked for LOS

1 = hill I has been checked for LOS



4PR#0  
FULDA FOREST DATA

NUMBER OF FORESTS 109

1	558.75	991.25	3.75	90	250	187.5
2	562.27	982.31	16.25	25	250	125
3	570.89	957.49	9.75	85	375	250
4	544.66	946.2	28.75	84	875	562.5
5	515	973.63	28.75	0	312.5	187.5
6	531.25	946.88	28.75	0	750	375
7	536.09	958	28.75	100	812.5	312.5
8	525.56	954.94	28.75	45	875	250
9	537.25	971.25	28.75	0	100	50
10	551.17	949.88	28.75	140	500	50
11	560.85	944.85	23.75	70	250	156.25
12	593.71	961.61	23.75	140	250	156.25
13	588.74	994.74	23.75	-2	750	250
14	524.38	1002.75	23.75	90	150	50
15	583.4	953.11	23.75	85	312.5	250
16	588.02	951.98	23.75	17	250	100
17	509.84	1031.1	21.25	17	375	187.5
18	579.97	1020.65	21.25	5	750	375
19	584.45	1029.09	21.25	-25	1250	500
20	582.17	952.4	21.25	-12	350	50
21	530.62	952.14	21.25	4	375	187.5
22	563.51	1013.17	18.75	-34	625	437.5
23	514.99	958.02	18.75	3	1000	500
24	523.97	960.38	18.75	-52	375	187.5
25	529.16	966.12	18.75	-3	250	250
26	516.78	976.03	18.75	-23	375	187.5
27	564.85	981.64	18.75	-20	250	250
28	543.75	992.43	18.75	-1	375	187.5
29	570	1012.25	18.75	90	100	100
30	572.5	1028.75	18.75	0	250	100
31	596.25	997.88	18.75	90	100	100
32	588.72	1014.86	18.75	-28	562	281.25
33	596.48	1008.2	18.75	117	500	312.5
34	520.25	995	18.75	0	150	50
35	521.25	1004	18.75	90	150	150
36	559	936.78	18.75	24	437	312.5
37	536.25	962.5	18.75	90	375	250
38	548.37	972.35	18.75	-2	437.5	250
39	501.74	934.89	18.75	130	312.5	187.5
40	596.25	946.88	18.75	90	187.5	187.5

Figure 18: Sample File from Forest Maker Program





$HL(I,J,K)$  = the number of the K-th hill in grid square I,J  
 which influences the terrain in that grid  
 square  $I = 1$  to  $L$ ;  $J = 1$  to  $W$ ;  $K = 1$   
 to  $HL(I,J,0)$

$HL(I,J,0)$  = the total number of hills in grid square I,J  
 which influence the terrain in that grid square

$HL(0,0,0)$  = the base elevation of the terrain map

$H2$  = temporary variable identifying the hill being checked  
 for line of sight

$L$  = number of grid squares on the terrain map in the  
 x direction (NGRIDX)

$LX$  = x-coord of lower left grid square of terrain map in  
 1000 meter units (X.LO.BDRY)

$LY$  = y-coord of lower left grid square of terrain map in  
 1000 meter units (Y.LO.BDRY)

$M\$$  = name of files containing terrain data

$NH$  = total number of hills on the terrain map (NHILLS)

$P1$  = computing parameter for a hill (PXX.H)

$P2$  = computing parameter for a hill (PXY.H)

$P3$  = computing parameter for a hill (PYY.H)

$QI$  = quadratic function of the ellipse represnting the  
 hill (QI)



W = number of grid squares on the terrain map in the Y  
direction (NGRIDY)

X = current x-coord of unit whose elevation is being  
computed (in 100 meter units) (X)

XB(I) = current x-coord for BLUE unit I

XR(I) = current x-coord for RED unit I

XS = distance in x direction between unit location and  
center of hill mass (XS)

X1 = relative number of grid squares in x direction of a  
BLUE unit location with respect to the lower left  
grid square

X2 = relative number of grid squares in x direction of a  
RED unit location with respect to the lower left  
grid square

X3 = number of grid squares in x direction between a BLUE  
unit and a RED unit

X4,Y4 = current grid square being checked for line of  
sight in LOS subroutine

Y = current y coord of unit whose elevation is being  
computed (in 100 meter units) (Y)

YB(I) = current y-coord for BLUE unit I

YR(I) = current y-coord for RED unit I



YS = distance in y direction between unit location and  
center of hill mass (YS)

Y1 = relative number of grid squares in y direction of a  
BLUE unit location with respect to the lower left  
grid square

Y2 = relative number of grid squares in y direction of a  
RED unit location with respect to the lower left  
grid square

Y3 = number of grid squares in y direction between a BLUE  
unit and a RED unit

Z = temporary variable for the elevation at a point on a  
hill (Z)

ZB(I) = elevation of BLUE unit I

ZR(J) = elevation of RED unit J



## APPENDIX E

### SYNOPSIS OF THE POSTPROCESSOR

The following appendix is a summary of the work done by other students as a part of a joint project for OA 4655. The authors gratefully acknowledge the work done by Captains Ambrose R. Hock and Steven L. Maddox in developing this postprocessor to reduce the amount of work required in extracting the necessary data from STAR. Their work is included here in this appendix since it is an integral part of the parameter estimation process.

The postprocessor developed for this thesis is a Simscript language program that provides to the user a summary of the data generated from the Simulation of Tactical Alternative Responses (STAR) Model. Additionally, the postprocessor performs some routines that assist the user in the data analysis of the model. The STAR Model is a Simscript language program that simulates combat between two combined arms teams in a combat environment that includes field artillery fire and electronic warfare.

Since the model assumed in the project only required data generated by a tank vs tank battle, it was necessary to





change certain aspects of the STAR model. Thus it was necessary to "turn off" the field artillery and Electronic Warfare modules within the STAR model. Also the non-tank units needed to be deleted. Referring to figure 19, the Electronic Warfare code (EWCOD) was deleted through the use of a comment card, and a Electronic Warfare off (EWOFF) subroutine was inserted.

```
//STAR THES JOB (3102,0234),'COMB ARMS BATTLE',CLASS=C
//SIM.SYS PRINT DD DUMMY
//SIM.SYS IN DD DISP=SHR,DSN=MSS.S3102.THESIS(WRKPREAM)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(SNAPDOTR)
//* DD DISP=SHR,DSN=MSS.S3102.THESIS(EWCOD)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(MOVCOORD)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(COMMWORK)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(TEMPCOMM)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(TEMPGRND)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(EWOFF)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(FAEXPER)
// DD DISP=SHR,DSN=MSS.S3102.THESIS(ARTYMSG)
```

Figure 19: Electronic Warfare Deletion

Thus, whenever the main program called for the usage of EW, the EWOFF subroutine automatically returned the program back to the point where the EW routine was called and the simulation continued with no Electronic Warfare generated. The field artillery within the STAR model was cancelled by



having the simulation create FA fire at time equal to 5000 time units(see Figure 20).

Schedule a FABEGIN in 5000.0001 time units

Figure 20: Field Artillery Deletion

Since the simulation was scheduled to run only 2500 time units, no field artillery was generated. Finally, the internal logic of the STAR model was used to "destroy" the non-tank units within the simulation by changing their basic load to zero(see Figure 21). This action created situations, where the tank elements did not consider the non-tank elements as lethal or dangerous targets and thus were ignored.

1 1	1 1 0 38	1 1 0 17	1 1 0 100	0 0 0 0
2 3	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
2 4	1 0 1 10	0 0 0 0	0 0 0 0	0 0 0 0
3 6	0 0 0 0	1 0 1 2	0 0 0 0	0 0 0 0
4 1	50 20 0 50	60 30 0 50	0 0 0 0	0 0 0 0
1 7	1 1 0 22	1 1 0 18	1 1 0 100	0 0 0 0
2 8	1 0 1 4	0 0 0 0	1 1 0 11	0 0 0 0
1 1	1 1 0 38	1 1 0 17	1 1 0 100	0 0 0 0
2 3	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
2 4	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
3 6	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
4 1	50 20 0 50	60 30 0 50	0 0 0 0	0 0 0 0
1 7	1 1 0 22	1 1 0 18	1 1 0 100	0 0 0 0
2 8	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0

Figure 21: Alteration of Basic Load

Output from the STAR model can be divided into three categories:



Update list of attacker/defender status.

Shot data

Significant event listing (i.e. movement, EW and FA events)

Only the shot data from the STAR model is needed to provide the necessary data for computations. Figure 22 is a sample of this output. In order to utilize this data, the internal output control of the model was used to place the shot data in a mass storage location within the computer to be later manipulated by the postprocessor.

The flow chart for the postprocessor is contained in Figure 23; a copy of the program itself can be found in Appendix F as Listing I. The program flow is very basic and needs little explanation. From the mass storage location of the computer, the postprocessor reads pertinent information into the SHOTLIST. Once all of the data has been read, the program processes the data into a casualty list (CASLIST) keying from a status of "dead" from the Shotlist. Figure 24 is a sample of the casualty list output. Once CASLIST is created the postprocessor performs histogram computations and graphs. The postprocessor can print two types of histograms. Figure 25 contains the Simcsript Library program for the histogram. Additionally, the HISTG routine in



1	257	2704	34	1-7	1	30	1-1	.26	57391	100581	377	5.0	5	57730	97900	439
0.2	3	268	37	1-1	1	30	1-7	1.00	57730	97900	439	0.	3	57456	100495	380
5.0	3	276	41	SS	0.	30	1-7	.30	57320	97900	427	0.	3	57435	100459	380
5.0	5	289	27	1-1	1	31	1-7	1.00	57140	97920	429	0.	3	57476	100430	382
5.0	5	303	41	SS	0.	38	1-1	.07	57543	100347	344	5.0	5	57320	97900	427
5.0	5	307	29	1-1	1	61	1-7	1.00	57600	97850	433	0.	3	57431	100350	380
5.0	7	316	44	1-7	1	24	1-1	.07	57957	100034	393	5.0	5	57320	97900	427
0.3	318	2390	63	1-7	1	28	1-1	.07	57506	100282	343	5.0	5	57320	97900	427
0.4	321	2391	62	1-7	1	28	1-1	.07	57452	100297	381	5.0	5	57320	97900	427
0.10	322	2352	45	1-7	1	33	1-1	.07	57996	100048	394	5.0	5	57320	97900	427
0.11	324	2236	46	1-7	1	23	1-1	.07	574036	100017	394	5.0	5	57320	97900	427
0.12	328	2305	64	1-7	1	30	1-1	.36	57513	100194	383	5.0	5	57730	97900	439
0.13	332	2335	30	1-1	1	63	1-7	1.00	57730	97900	439	0.	3	57471	100220	381
0.14	334	23185	46	1-7	1	34	1-1	.07	57920	100001	392	5.0	5	57320	97900	427
0.15	335	2314	63	1-7	1	28	1-1	.07	57465	100209	381	5.0	5	57320	97900	427
0.16	340	2134	43	1-7	1	23	1-1	.07	57858	99985	391	5.0	5	57320	97900	427
0.17	341	2150	45	1-7	1	24	1-1	.07	57958	99964	393	5.0	5	57320	97900	427
0.18	344	2136	46	1-7	1	23	1-1	.07	57995	99926	393	5.0	5	57320	97900	427
0.19	355	2113	27	1-1	1	44	1-7	.68	57140	97920	428	0.	3	57877	99905	390
0.20	356	22076	46	1-7	1	26	1-1	.07	57375	99900	389	5.0	5	57320	97900	427
0.21	361	2222	DEAD	0.	0.	28	1-1	.07	57140	0	12	4		57320	97900	427
0.22	426	2756	DEAD	0.	0.	56	1-7	1.00	54150	100690	340	0.	3	56777	99858	355
0.23	438	2646	20	1-1	1	34	1-7	.98	54440	98000	378	0.	3	56869	99812	361
0.24	445	2625	55	1-7	1	39	1-1	.36	56724	99835	353	5.0	5	54190	100520	341
0.25	454	2629	56	1-7	1	39	1-1	.36	56716	99790	355	5.0	5	54190	100520	341
0.26	454	2629	59	1-1	1	56	1-7	.37	56190	100520	341	0.	3	56715	99790	355
0.27	455	2630	4	1-1	1	55	1-7	.42	56150	100620	341	0.	3	56700	99796	354
0.28	455	2635	58	1-7	1	27	1-1	.36	56411	99748	362	5.0	5	57140	97920	428
0.29	467	2622	27	1-1	1	53	1-7	.97	57140	97920	428	0.	3	56770	99702	361
0.30	469	2603	19	1-1	1	58	1-7	.95	54360	98100	377	0.	3	56770	99702	361
0.31	469	2647	63	1-7	1	20	1-1	.07	56400	99777	364	5.0	5	54940	98000	378
0.32	466	2632	64	1-7	1	20	1-1	.07	56420	99734	367	5.0	5	54940	98000	378
0.33	466	2633	42	1-7	1	30	1-1	.07	57559	99322	401	5.0	5	57730	97900	439
0.34	502	2656	57	1-7	1	29	1-1	.07	56504	99646	351	5.0	5	57600	97850	438
0.35	504	2657	64	1-7	1	20	1-1	.36	56440	99705	365	5.0	5	54940	98000	378
0.36	504	2652	18	1-1	1	64	1-7	1.00	54740	98180	376	0.	3	56839	99702	365

Figure 22: STAR Output Shotlist







FORTTRAN can be accessed to produce a histogram of the data. After the histogram data is generated, the postprocessor calculates the attrition rate coefficients using the formulas discussed in Section III-E of this thesis.

Brief description of the postprocessor (see this appendix for variable description):

Preamble:

lines 1 - 9 definition of permanent entities.  
lines 10 - 39 definition of temporary entities.  
lines 40 - 54 definition of data to be collected for histograms.

Main:

line 2 variable definition.  
line 3 - 4 system parameters read.  
lines 13 - 31 creation of shotlist, reading data from file.  
lines 43 - 89 creation of casualty list, file "dead".  
lines 90 - 125 processing of histogram data  
lines 125 - 186 processing of attrition rate coefficients.



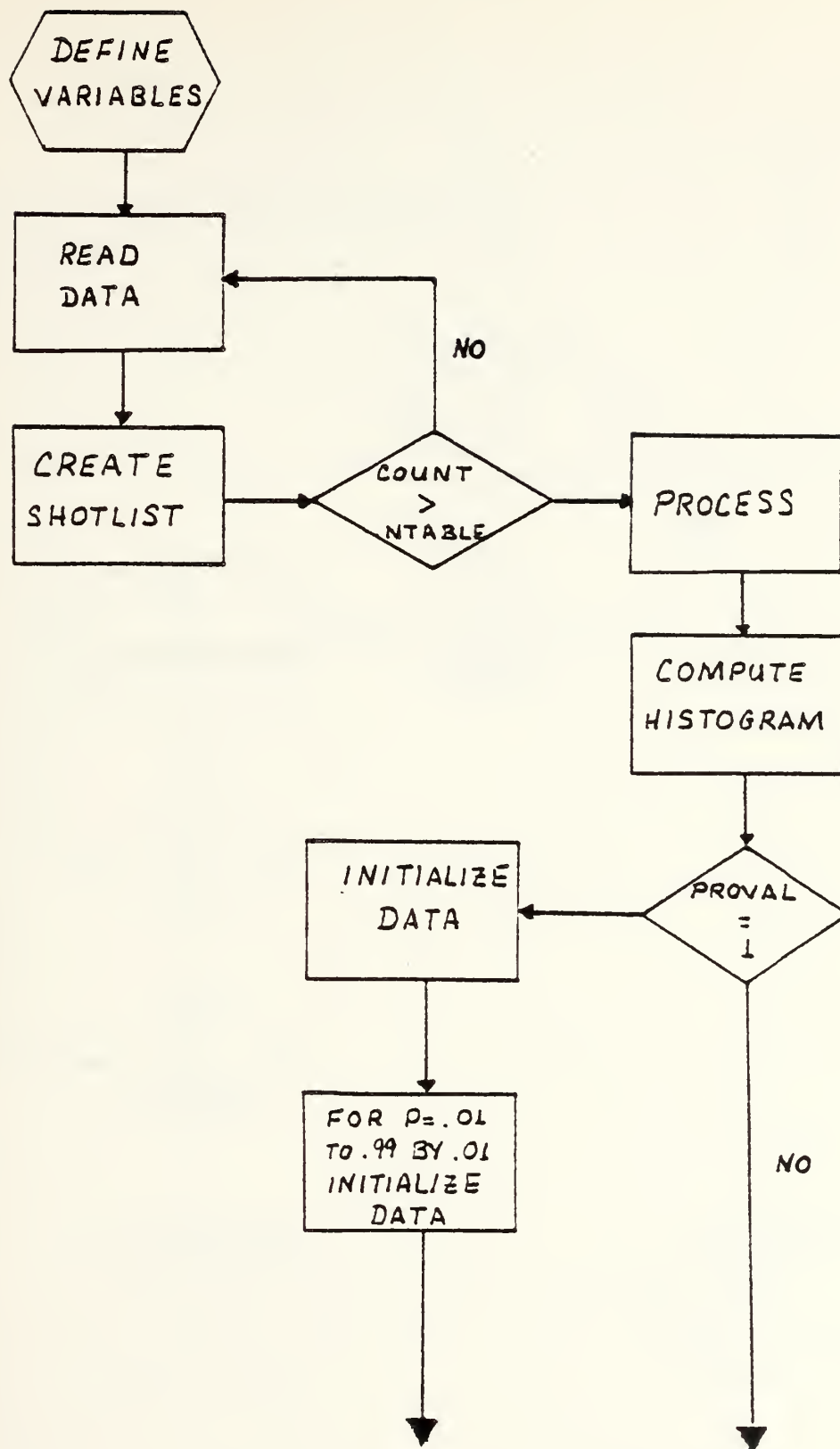
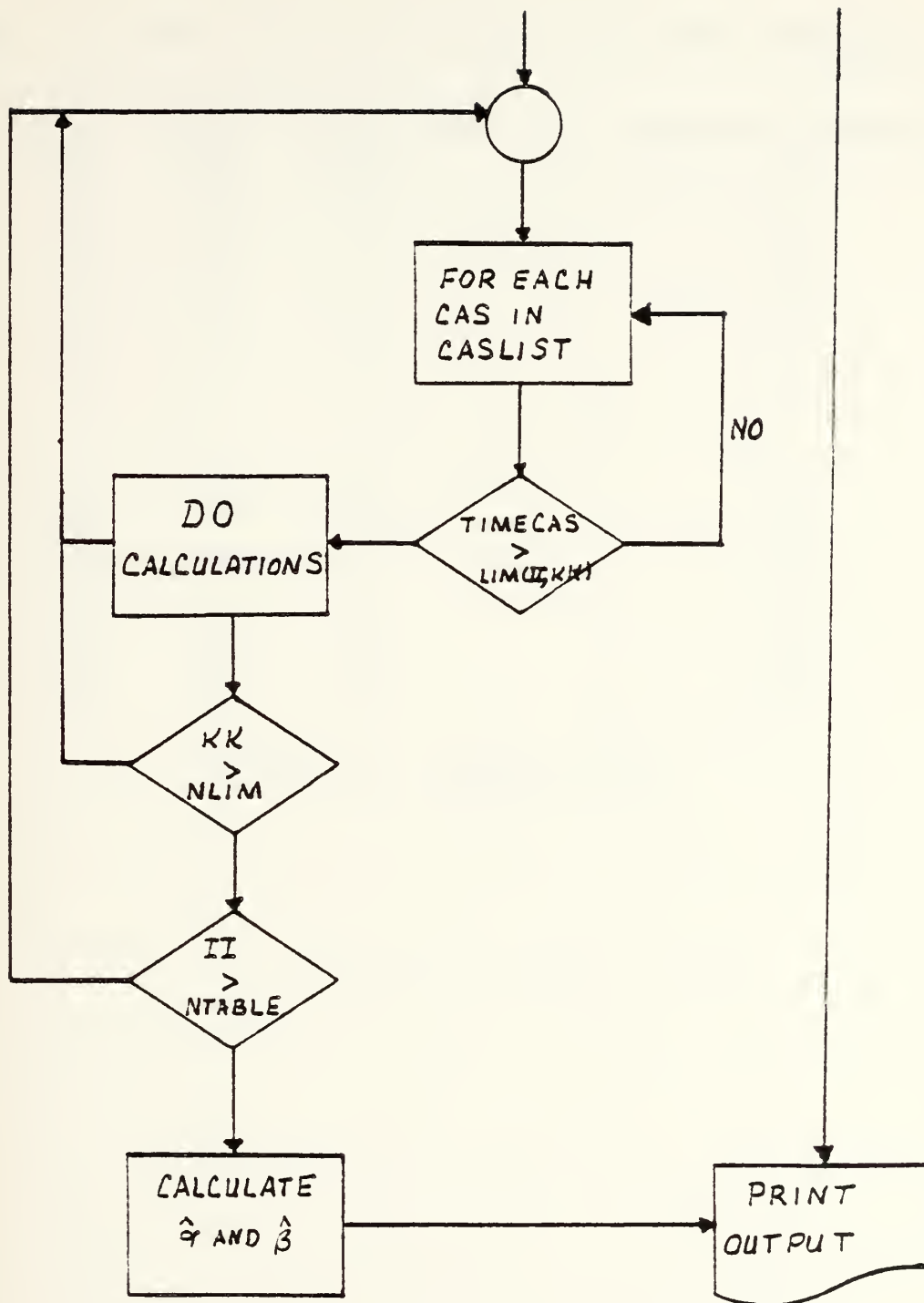


Figure 23: Flow Chart of the Postprocessor







# SHOT LIST DATA FOR CASUALTIES FOR THIS STAR SIMULATION

NUM	TIME	TARGET	SYS-WPN	TYPE	TIME BETWEEN	CASUALTIES
1	322	59	1-7			0
2	334	46	1-7			12
3	468	58	1-7			134
4	574	28	1-1			106
5	581	42	1-7			7
6	591	27	1-1			10
107	1210	72	1-7			6
108	1238	69	1-7			28
109	1265	73	1-7			27
110	1303	75	1-7			38
111	1323	19	1-1			20
112	1421	76	1-7			98

Figure 24: Casualty List





NUMBER OF BLUE KILLED = 28  
 BLMU = 47.25000 BLSIG = 299.259  
 NUMBER OF RED KILLED = 84  
 RDMU = 13.24096 RDSIG = 219.106

HISTOGRAM OF BLUE AND RED CASULTIES  
 (DATA BASED ON TIME BETWEEN BLUE CASULTIES  
 AND TIME BETWEEN RED CASULTIES)

INTERVAL=10 UNITS	#BLUE CAS	#RED CAS
1	3	11
2	4	8
3	4	20
4	0	4
5	0	8
6	0	4
7	0	0
8	0	8
9	0	0
10	0	0
11	0	4
12	4	8
13	0	4
14	4	4
15	0	0
16	0	0
17	0	0
18	0	0
19	4	0
20	0	0
21	5	0

Figure 25: Simscript Histogram

List of Variables For Postprocessor

AHAT = estimate of the attrition coefficient for RED

attriting BLUE

BHAT = estimate of the attrition coefficient for BLUE

attriting RED

BLHST = Simscript routine for the histogram of BLUE time  
 between casualties

BLMU = Simscript routine for calculating the mean time



between casualties

BLSHTHST = Simscript routine for the histogram of BLUE  
shot times

BLSHTIG = Simscript routine for calculation of the  
standard deviation of BLUE shot times

BLSHTMU = Simscript routine for calculation of the mean  
of BLUE shot times

BLSIG = Simscript routine for calculation of the  
standard deviation of BLUE time between casualties

BLUE.SHOTS = time of the previous BLUE shot

BLUE.TIME = time of the previous BLUE casualty

CAS = casualty

CASHST = Simscript routine for the histogram of  
total time between casualties

CASIG = Simscript routine for calculation of the  
standard deviation of the total time between  
casualties

CASLIST = array containing list of casualties

CASMU = Simscript routine for calculation of the mean  
for the total time between casualties

CBBLUE = number of surviving BLUE force elements

CK = integer used in the calculation of the attrition  
coefficient



1 = BLUE casualty

0 = RED casualty

CRED = number of surviving RED force elements

CURTIME = time of previous casualty

FNAME = firer's name

FSWTYPE = firer's system-weapon type

J.BL = number of BLUE casualties(used in BLHST routine)

J.RD = number of RED casualties(used in RDHST routine)

JBLHST = number of BLUE shots(used in BLSHST routine)

JCAS = number of casualties(used in CASHST routine)

JRDSHT = number of RED shots(used in RDSHST routine)

JSHOT = number of shots( used in SHOTHST routine)

JTOT = number of casualties(used in TOTHST routine)

LIM = array of time periods that represent phases of  
the battle

LIMA = lower time limit of phase

LIMB = upper limit of phase

LP = partial derivative of p

LQ = partial derivative of q

MAXBLUE = initial BLUE force size

MAXRED = initial RED force size

MINP = minimum of p

MINQ = minimum of q



MK1 = number of RED elements in time interval  
NK1 = number of BLUE elements in the time interval  
NLIM = number of time intervals to be evaluated  
NSHOT = number of shots in the total battle  
NTABLE = number of tables(battles) to be evaluated  
NUM = counter for number of casualties  
NUMBL.CAS = number of BLUE casualties  
NUMRD.CAS = number of RED casualties  
NUMCAS = casualty entity number  
P = probability of not acquiring a target  
PHAT = estimated p  
PROVAL = process variable  
    0 = stop  
    1 = process  
QHAT = estimate of q  
RANGE = range of firer to target  
RDHST = Simscript routine for the histogram of RED  
    casualties  
RDMU = Simscript routine for calculation of the average  
    time between RED casualties  
RDSHTHST = Simscript routine for the histogram of total  
    red shots  
RDSHTMU = Simscript routine for calculation of the average





red shot time

RDSHTSIG = Simscript routine for the calculation of the  
standard deviation of the RED shot time

RDSIG = Simscript routine for calculation of the  
standard deviation for RED time between casualties

RED.SHOTS = time of previous RED shot

RED.TIME = time of previous RED casualty

RUNNO = run number

SHOT = shot

SHOTHST = Simscript routine for total shots fired

SHOTLIST = array of shot times

SHOTMU = Simscript routine for calculation of the average  
time of shots

SHOTSIG = Simscript routine for calculation of the  
standard deviation of total shots

STATUS = status of shot

STATUS.CAS = status of casualty

T.BTWN.CAS = time between casualty

T.CAS = casualty number

TBLUE = number of BLUE casualties within the interval

TGT.CAS = target casualty

TIME = time of shot

TIMECAS = time of casualty



TIMELIM = maxtime of battle when a casualty occurred

TMCAS = time of previous casualty

TMRDCAS = time of previous RED casualty

TOTAL.CASTIME = total casualty time

TOTAL.SHOT.TIME = total shot time

TOTAL.TIME = total casualty time for the creation of

T.BTWN.CAS

TOTHST = Simgscript routine for the histogram of

total casualty time

TOTMU = Simgscript routine for calculation of the

average casualty time

TOTSIG = Simgscript routine for calculation of the

standard deviation of the total casualty time

TRED = total RED casualties within the time interval

TSUB = time counter

TSWTYPE = target system-weapon type

TTBLUE = total BLUE casualties for XX battles

TTRED = total RED casualties for XX battles

TTCAS = total casualties for XX battles

TTT = number of shot

TYPE.CAS = system weapon type of the casualty

VAR = attrition coefficient variables



## APPENDIX F

### LISTING OF COMPUTER PROGRAMS

#### A. DAMSTAC MODEL PROGRAM

```
10 REM UPDATED 24 FEB 82
20 REM DETERMINISTIC AGGREGATED MODEL OF STAR ON THE
21 REM APPLE COMPUTER (DAMSTAC)
30 DIM XB(5),YB(5),XR(5),YR(5),BX(5,10),BY(5,10),RX(5,10)
40 DIM BP(5),RP(5),SB(5),SR(5),RY(5,10)
50 DIM BF(5),RF(5),BT(5,5),RT(5,5),DB(5),DR(5)
60 DIM BR(5),RR(5)
70 DIM B1(5),R1(5)
80 T = 0:DT = 30:MT = 1500
90 OS = CHR$(4)
100 P = 0.99:Q = 0.93
110 PI = 3.141592654:PR = 0
120 A = 2.4:B = 1.2
130 BE = 0.3:RE = 0.3
140 BM = .5:RM = .5
150 KK = 0
160 NK = MT / DT
161 REM ZZ=FLAG FOR TYPE OUTPUT
162 REM ZZ=1 GIVES UNIT
163 REM LOCATIONS & SIZES
164 REM ZZ=0 GIVES TIME & TOTAL
165 REM RED & BLUE FORCE LEVELS
166 ZZ = 0
170 DIM B0(NK),R0(NK)
180 HOME
181 REM READ DATA FROM FILE FOR
182 REM BLUE FORCE.
183 REM DATA INCLUDES:
184 REM M=NUMBER OF UNITS
185 REM B1=NUMBER OF COORD PTS
186 REM BX,BY=GRID OF COORD PT
187 REM
188 INPUT "NAME OF FILE FOR BLUE DATA? ";N$
189 PRINT OS;"OPEN ";N$;".BLUE"
210 PRINT OS;"READ ";N$;".BLUE"
220 INPUT M
230 FOR I = 1 TO M
240 INPUT B1
250 FOR J = 1 TO B1
260 INPUT BX(I,J): INPUT BY(I,J)
270 NEXT J: NEXT I
280 PRINT OS;"CLOSE ";N$;".BLUE"
```



```

281 REM SET INITIAL UNIT
282 REM LOCATION EQUAL TO
283 REM 1ST COORD PT.
284 REM
290 FOR I = 1 TO M:BX(I) = BX(I,1):YB(I) = BY(I,1):BP(I) = 1
300 PRINT B1: FOR JJ = 1 TO B1: PRINT BX(I,JJ),BY(I,JJ): NEXT JJ
310 PRINT "SIZE OF BLUE UNIT ":I: INPUT SB(I)
320 B1(I) = SB(I)
321 REM
322 REM SUM INITIAL FORCE SIZE
323 REM
330 B0(0) = B0(0) + SB(I)
331 REM
332 REM RATE OF BLUE MOVEMENT
333 REM EQUALS 0
334 REM
340 BR(I) = 0
350 NEXT
360 PRINT
361 REM
362 REM READ DATA FROM FILE FOR
363 REM RED FORCE.
364 REM SAME FORMAT AS BLUE
365 REM
370 INPUT "NAME OF FILE FOR RED DATA? ":N$
380 PRINT O$;"OPEN ":N$;".RED"
390 PRINT O$;"READ ":N$;".RED"
400 INPUT N
410 FOR I = 1 TO N
420 INPUT R1
430 FOR J = 1 TO R1
440 INPUT RX(I,J): INPUT RY(I,J)
450 NEXT : NEXT
460 PRINT O$;"CLOSE ":N$;".RED"
470 FOR I = 1 TO N:XR(I) = RX(I,1):YR(I) = RY(I,1):RP(I) = 1
480 PRINT "SIZE OF RED UNIT ":I: INPUT SR(I)
490 R1(I) = SR(I)
500 R0(0) = R0(0) + SR(I)
510 RX(I) = 5
520 NEXT I
530 PRINT : INPUT "DO YOU WANT THE PRINTER ON? (Y/N) ":A$
535 IF A$ = "Y" THEN PR = 1
540 HOME : UTAB 3
550 IF PR = 1 THEN PR# 1
560 PRINT
564 REM
565 REM PRINT INITIAL DATA
566 REM
570 PRINT "TIME": POKE 36,7: PRINT "BLUE": POKE 36,20: PRINT "RED"

```





```

580 PR# 0
584 REM
585 REM WHICH OUTPUT TYPE?
586 REM
590 IF ZZ = 1 THEN GOSUB 1750: GOTO 610
600 GOSUB 1490
610 REM MAIN PROGRAM
620 T = T + DT
624 REM
625 REM CHECK IF MAX TIME
626 REM IS EXCEEDED
627 REM
630 IF T < = MT THEN 640
635 PRINT "END OF BATTLE DUE TO TIME": GOSUB 1540: END
640 GOSUB 790: REM MOVEMENT SUBROUTINE
650 GOSUB 1170: REM ATTRITION SUBROUTINE
654 REM
655 REM INCREMENT THE TIME
656 REM PERIOD INDEX
657 REM
660 KK = KK + 1
670 B0(KK) = 0: R0(KK) = 0
674 REM
675 REM SUM BLUE FORCE LEVEL
676 REM FOR THIS TIME PERIOD
677 REM
680 FOR I = 1 TO M
690 B0(KK) = B0(KK) + SB(I)
700 NEXT I
704 REM
705 REM SUM RED FORCE LEVEL
706 REM FOR THIS TIME PERIOD
707 REM
710 FOR J = 1 TO N
720 R0(KK) = R0(KK) + SR(J)
730 NEXT J
734 REM
735 REM WHICH TYPE OF OUTPUT?
736 REM
740 IF ZZ = 1 THEN GOSUB 1750: GOTO 750
750 GOSUB 1490

```



```

752 REM
753 REM CHECK IF END OF BATTLE
754 REM - CRITERIA FOR FORCE
755 REM LEVELS IS EXCEEDED
756 REM IF CRITERIA IS EXCEEDED
757 REM GOTO SAVE RESULTS
758 REM
759 IF B0(KK) > BE * B0(0) THEN 770
765 PRINT : PRINT "END OF BATTLE DUE TO ATTRITION OF BLUE"
766 GOSUB 1540: END
770 IF R0(KK) > RE * R0(0) THEN 780
775 PRINT : PRINT "END OF BATTLE DUE TO ATTRITION OF RED"
776 GOSUB 1540: END
780 GOTO 620
790 REM MOVEMENT SUBROUTINE
794 REM
795 REM FOR RED UNITS
796 REM
800 FOR I = 1 TO N
804 REM
805 REM GET LAST COORD PT
806 REM
810 J = RP(I)
813 REM
814 REM COMPUTE COMPONENTS OF
815 REM DISTANCE BETWEEN NEXT
816 REM COORD PT AND CURRENT
817 REM LOCATION
818 REM
820 DY = RY(I,J + 1) - YR(I)
830 DX = RX(I,J + 1) - XR(I)
833 REM
834 REM DO GEOMETRY TO GET
835 REM CORRECT ANGLE (AN)
836 REM
840 IF DX = 0 AND DY > 0 THEN AN = PI / 2: GOTO 880
850 IF DX = 0 AND DY < 0 THEN AN = 3 + PI / 2: GOTO 880
860 AN = ATN(DY / DX)
870 IF DX < 0 THEN AN = PI + AN
873 REM
874 REM COMPUTE DH, DISTANCE
875 REM TO BE TRAVELLED IN
876 REM THIS TIME PERIOD
877 REM
880 D1 = DT * RR(I) * COS(AN)
890 D2 = DT * RR(I) * SIN(AN)
900 DH = SQR(D1 ^ 2 + D2 ^ 2)

```



```

904 REM
905 REM COMPUTE OI, DISTANCE
906 REM TO NEXT COORD PT
907 REM FROM CURRENT LOCATION
908 REM
909 OI = SQR (OX ^ 2 + OY ^ 2)
910 REM
911 REM IF OI < OH, MOVE UNIT
912 REM ONLY THE AMOUNT TO
913 REM NEXT COORD PT
914 REM IF OI IS USED, UPDATE
915 REM LAST COORD PT
916 REM
917 REM
918 IF OI > = OH THEN 950
919 OI = OX:O2 = OY
920 BP(I) = J + 1
921 YR(I) = INT (YR(I) + O2)
922 XR(I) = INT (XR(I) + O1)
923 NEXT
924 REM
925 REM DO THE SAME FOR BLUE
926 REM
927 FOR I = 1 TO M
928 IF BR(I) = 0 THEN 1150
929 J = BP(I)
1000 OY = BY(I,J + 1) - YB(I)
1010 OX = BX(I,J + 1) - XB(I)
1020 IF OX = 0 AND OY > 0 THEN AN = PI / 2: GOTO 1060
1030 IF OX = 0 AND OY < 0 THEN AN = 3 * PI / 2: GOTO 1060
1040 AN = ATN (OY / OX)
1050 IF OX < 0 THEN AN = PI + AN
1060 O1 = OT * BR(I) * COS (AN)
1070 O2 = OT * BR(I) * SIN (AN)
1080 OH = SQR (O1 ^ 2 + O2 ^ 2)
1090 OI = SQR (OX ^ 2 + OY ^ 2)
1100 IF OI > = OH THEN 1130
1110 OI = OX:O2 = OY
1120 BP(I) = J + 1
1130 YB(I) = INT (YB(I) + O2)
1140 XB(I) = INT (XB(I) + O1)
1150 NEXT
1160 RETURN

```



```

1170 REM   ATTRITION SUBROUTINE
1172 REM
1173 REM   ZERO OUT ATTRITION
1174 REM   VALUES FOR ALL UNITS
1175 REM
1180 FOR I = 1 TO M:BF(I) = 0:OB(I) = 0: NEXT
1190 FOR J = 1 TO N:RF(J) = 0:OR(J) = 0: NEXT
1192 REM
1193 REM   CHECK RANGE BETWEEN
1194 REM   OPPONENTS. IF RANGE
1195 REM   <= 2700 ATTRITION WILL
1196 REM   OCCUR. REDUCE RATE OF
1197 REM   RED MOVEMENT TO 2 M/S
1198 REM
1200 FOR I = 1 TO M
1210   FOR J = 1 TO N
1220     BT(I,J) = 0:RT(J,I) = 0
1230     RG = SQR ((XB(I) - XR(J)) ^ 2 + (YB(I) - YR(J)) ^ 2)
1240     IF RG > 2700 THEN 1310
1250     RR(J) = 2
1251     REM
1252     REM   INCREMENT THE NUMBER
1253     REM   OF TGT'S FIRED AT BY
1254     REM   EACH UNIT. COMPUTE
1255     REM   ATTRITION CAUSED BY
1256     REM   RED ON BLUE & VICE
1257     REM   VERSA
1258     REM
1270     BF(I) = BF(I) + 1
1280     RF(J) = RF(J) + 1
1285     IF RR(J) = - 8 THEN BT(I,J) = 0: GOTO 1295
1290     BT(I,J) = A / N * (1 - (P) ^ SB(I)) * SR(J)
1295     IF SR(I) = 8 THEN RT(J,I) = 0: GOTO 1310
1300     RT(J,I) = B / M * (1 - (Q) ^ SR(J)) * SB(I)
1310   NEXT : NEXT
1311   REM
1312   REM   SUM TOTAL ATTRITION
1313   REM   FOR EACH UNIT
1314   REM
1320   FOR I = 1 TO M
1330     FOR J = 1 TO N
1340       IF RF(J) = 0 OR BF(I) = 0 THEN 1370
1350       OB(I) = OB(I) + BT(I,J) / RF(J)
1360       OR(J) = OR(J) + RT(J,I) / BF(I)
1370     NEXT : NEXT

```





```

1371 REM
1372 REM COMPUTE NEW UNIT
1373 REM STRENGTH. SUBTRACT
1374 REM UNIT ATTRITION FROM
1375 REM CURRENT UNIT STRENGTH
1376 REM IF UNIT STRENGTH GOES
1377 REM NEGATIVE, MAKE IT
1378 REM EQUAL 0.
1379 REM
1380 FOR I = 1 TO M
1390 SB(I) = SB(I) - DB(I)
1400 IF SB(I) < 0 THEN SR(I) = 0
1410 IF SB(I) < = BM * B1(I) THEN BR(I) = 8
1420 NEXT
1430 FOR J = 1 TO N
1440 SR(J) = SR(J) - DR(J)
1450 IF SR(J) < 0 THEN SR(J) = 0
1460 IF SR(J) < = RM * R1(J) THEN RP(J) = - 8
1470 NEXT
1480 RETURN
1490 REM PRINTOUT/SUMMARY
1500 IF PR = 1 THEN PR# 1
1510 PRINT T: POKE 36,7: PRINT R0(KK):
1515 POKE 36,20: PRINT R0(KK)
1520 PR# 0
1530 RETURN
1540 REM SAVE RESULTS IN A FILE
1550 PRINT
1555 INPUT "DO YOU WANT A FILE OF THIS RUN'S DATA? (Y/N) ":A$
1560 IF A$ = "N" THEN 1750
1570 O$ = CHR$(4)
1580 INPUT "NAME OF FILE FOR FORCE LEVEL DATA? ":F$
1590 PRINT O$;"OPEN ";F$;".COEFS"
1600 PRINT O$;"WRITE ";F$;".COEFS"
1610 PRINT A: PRINT B: PRINT P: PRINT Q
1620 PRINT O$;"CLOSE ";F$;".COEFS"
1630 PRINT O$;"OPEN ";F$;".RESULTS"
1640 PRINT O$;"WRITE ";F$;".RESULTS"
1650 PRINT NK + 1: PRINT NK + 1
1660 FOR I = 0 TO NK
1670 T = I + 3
1680 PRINT T: PRINT B0(I)
1690 NEXT I
1700 FOR I = 0 TO NK
1710 T = I + 3
1720 PRINT T: PRINT R0(I)
1730 NEXT I
1740 PRINT O$;"CLOSE ";F$;".RESULTS"
1750 RETURN

```



```

1760 REM PRINTOUT/SUMMARY
1770 HOME : UTAB 3
1780 IF PR = 1 THEN PR# 1
1790 PRINT "TIME IS " ; T
1800 PRINT : PRINT
1810 PRINT "BLUE FORCES"
1820 PRINT "UNIT"; TAB( 7); "XCOORD"; TAB( 15); "YCOORD"; TAB( 23); "SIZE"
1830 FOR I = 1 TO M
1840 PRINT " " ; I ; TAB( 7); XB(I); TAB( 15); YB(I); TAB( 24); SB(I)
1850 NEXT
1860 PRINT : PRINT "RED FORCES"
1870 PRINT "UNIT"; TAB( 7); "XCOORD"; TAB( 15); "YCOORD"; TAB( 23); "SIZE"
1880 FOR I = 1 TO N
1890 PRINT " " ; I ; TAB( 7); XR(I); TAB( 15); YR(I); TAB( 24); SR(I)
1900 NEXT
1910 PRINT : PRINT
1920 PR# 0
1930 INPUT "HIT RETURN TO CONTINUE"; Z$
1940 RETURN

```



## B. FORCE MAKER PROGRAM

```
10 REM FORCE DATA-FILE MAKER
20 DIM BX(5,10),BY(5,10),B1(10)
30 GOTO 170
40 HOME
50 INPUT "NAME OF FILE? ";N$
60 O$ = CHR$(4)
70 PRINT O$;"OPEN ";N$;". ";M$
80 PRINT O$;"WRITE ";N$;". ";M$
90 PRINT M
100 FOR I = 1 TO M
110 PRINT B1(I)
120 FOR J = 1 TO B1(I)
130 PRINT BX(I,J): PRINT BY(I,J)
140 NEXT J
150 NEXT I
160 PRINT O$;"CLOSE ";N$;". ";M$
170 HOME
180 UTAB 5
190 PRINT "MENU:"
200 PRINT "1 MAKE FILE FOR BLUE FORCES"
210 PRINT "2 MAKE FILE FOR RED FORCES"
220 PRINT "0 QUIT"
230 PRINT : INPUT "WHICH? ";Z
240 IF Z = 0 THEN END
250 IF Z = 1 THEN M$ = "BLUE"
260 IF Z = 2 THEN M$ = "RED"
270 HOME
280 PRINT "WHAT IS THE FORCE SIZE OF ";M$;: INPUT " ";M
290 FOR I = 1 TO M
300 PRINT : PRINT "FOR UNIT ";I
310 PRINT "HOW MANY COORDINATING POINTS ";
315 INPUT "(INCLUDING START LOCATIONS)? ";B1(I)
320 FOR J = 1 TO B1(I)
330 PRINT
340 PRINT "ENTER GRID COORDS FOR COORDINATING POINT # ";J
350 INPUT "X-COORD IS ";BX(I,J)
360 INPUT "Y-COORD IS ";BY(I,J)
370 NEXT J
380 NEXT I
```



```

390 HOME
400 PRINT : PRINT TAB( 12);"*** DATA CHECK ***"
410 PRINT : PRINT : PRINT
420 PRINT "UNIT PT"; TAB( 9);"X-COORD"; TAB( 17);"Y-COORD"
430 FOR I = 1 TO M
440 FOR J = 1 TO B1(I)
450 PRINT TAB( 2);I; TAB( 6);J; TAB( 10);BX(I,J); TAB( 18);BY(I,J)
460 NEXT J
470 NEXT I
480 INPUT "ANY CHANGES? (Y/N) ";Z$
490 IF Z$ = "N" THEN 40
500 PRINT
510 INPUT "WHICH UNIT? ";I
520 INPUT "WHICH POINT? ";J
530 INPUT "X-COORD IS ";BX(I,J)
540 INPUT "Y-COORD IS ";BY(I,J)
550 GOTO 390

```





## C. RESULTS READER PROGRAM

```
10 HOME : UTAB 3
20 D$ = CHR$(4)
30 INPUT "NAME OF FILE FOR FORCE LEVEL DATA? ";F$
40 PRINT D$;"OPEN ";F$;".COEFS"
50 PRINT D$;"READ ";F$;".COEFS"
60 INPUT A: INPUT B: INPUT P: INPUT Q
70 PRINT D$;"CLOSE ";F$;".COEFS"
80 PRINT D$;"OPEN ";F$;".RESULTS"
90 PRINT D$;"READ ";F$;".RESULTS"
100 INPUT N: INPUT M
110 NK = N - 1
120 DIM B0(NK),R0(NK)
130 FOR I = 0 TO NK
140 INPUT T: INPUT B0(I)
150 NEXT I
160 FOR I = 0 TO NK
170 INPUT T: INPUT R0(I)
180 NEXT I
190 PRINT D$;"CLOSE ";F$;".RESULTS"
200 INPUT "PRINTER ON? ";A$
210 HOME : UTAB 3
220 IF A$ = "Y" THEN PR# 1
230 PRINT "A = ";A
240 PRINT "B = ";B
250 PRINT "P = ";P
260 PRINT "Q = ";Q
270 PRINT
280 PRINT "TIME": POKE 36,7: PRINT "BLUE":
285 POKE 36,20: PRINT "RED"
290 FOR KK = 0 TO NK
300 T = 30 * KK
310 PRINT T: POKE 36,7: PRINT B0(KK);
315 POKE 36,20: PRINT R0(KK)
320 NEXT KK
330 PR# 0
340 END
```



# D. MAP MAKER PROGRAM

```

10 REM MAP CATALOG MAKER/READER
20 DIM HL(10,10,12)
30 HOME : UTAB 3
40 PRINT "MENU:"
50 PRINT "1 MAP MAKER"
60 PRINT "2 MAP READER"
70 PRINT "0 QUIT"
80 PRINT : INPUT "WHICH? ";X
90 IF X = 0 THEN END
100 ON X GOTO 120,200
110 REM MAP CATALOG MAKER
120 HOME : UTAB 2
130 PRINT TAB(11);"*** MAP MAKER ***"
140 PRINT : PRINT
150 INPUT "NEW OR OLD MAP? (N/O) ";Z$
160 IF Z$ = "N" THEN II = 1:JJ = 1: GOTO 220
170 INPUT "NAME OF MAP? ";M$
180 O$ = CHR$(4)
190 GOSUB 620
200 INPUT "ENTER STARTING GRID SQUARE (I,J) ";II,JJ
210 GOTO 250
220 INPUT "SIZE OF MAP (1000 M SQUARES)? ";L,W
230 INPUT "ENTER LOWER LEFT GRID SQUARE (EG. 50,93) ";LX,LY
240 INPUT "BASE ELEVATION OF MAP? ";HL(0,0,0)
250 FOR I = II TO L
260 FOR J = JJ TO W
270 PRINT : PRINT
280 PRINT "FOR GRID SQUARE ";I;",";J
290 INPUT "NUMBER OF HILL MASSES? ";HL(I,J,0);KK = HL(I,J,0)
300 IF KK = 0 THEN 380
310 PRINT "ENTER THE ";KK;" HILLS FOR GRID SQUARE ";I;",";J
320 FOR K = 1 TO KK
330 PRINT "HILL ";K;" IS ";: INPUT HL(I,J,K)
340 NEXT K
350 JJ = 1
360 PRINT : INPUT "SAVE? (Y/N)";A$
370 IF A$ = "Y" THEN 400
380 NEXT J
390 NEXT I

```



```

400 HOME : UTAB 4
410 INPUT "NAME OF MAP FILE? ";M$
420 O$ = CHR$(4)
430 PRINT O$;"OPEN ";M$;".MAP"
440 PRINT O$;"WRITE ";M$;".MAP"
450 PRINT L: PRINT W
460 PRINT LX: PRINT LY
470 PRINT HL(0,0,0)
480 FOR I = 1 TO L
490 FOR J = 1 TO W
500 PRINT HL(I,J,0)
510 IF HL(I,J,0) = 0 THEN 550
520 FOR K = 1 TO HL(I,J,0)
530 PRINT HL(I,J,K)
540 NEXT K
550 NEXT J
560 NEXT I
570 PRINT O$;"CLOSE ";M$;".MAP"
580 PRINT : PRINT : PRINT : PRINT "... DONE": PRINT : PRINT
590 INPUT "DO YOU WANT TO CONTINUE INPUTTING DATA? (Y/N) ";Z$
600 IF Z$ = "Y" THEN 200
610 GOTO 30
620 O$ = CHR$(4)
630 PRINT O$;"OPEN ";M$;".MAP"
640 PRINT O$;"READ ";M$;".MAP"
650 INPUT L: INPUT W
660 INPUT LX: INPUT LY
670 INPUT HL(0,0,0)
680 FOR I = 1 TO L
690 FOR J = 1 TO W
700 INPUT HL(I,J,0)
710 IF HL(I,J,0) = 0 THEN 750
720 FOR K = 1 TO HL(I,J,0)
730 INPUT HL(I,J,K)
740 NEXT K
750 NEXT J
760 NEXT I
770 PRINT O$;"CLOSE ";M$;".MAP"
780 RETURN
790 REM MAP CATALOG FILE READER
800 HOME : UTAB 2
810 PRINT TAB( 11);"*** MAP READER ***"
820 PRINT : PRINT

```



```

930 INPUT "NAME OF MAP FILE? ";M$
940 INPUT "PRINTER ON? (Y/N) ";A$
950 O$ = CHR$(4)
960 PRINT O$;"OPEN ";M$;".MAP"
970 PRINT O$;"READ ";M$;".MAP"
980 INPUT L: INPUT W
990 INPUT LX: INPUT LY
900 INPUT HL(0,0,0)
910 FOR I = 1 TO L
920 FOR J = 1 TO W
930 INPUT HL(I,J,0)
940 IF HL(I,J,0) = 0 THEN 980
950 FOR K = 1 TO HL(I,J,0)
960 INPUT HL(I,J,K)
970 NEXT K
980 NEXT J
990 NEXT I
1000 PRINT O$;"CLOSE ";M$;".MAP"
1010 HOME
1020 IF A$ = "Y" THEN PR# 1
1030 PRINT "NAME OF MAP: ";M$
1040 PRINT "LOWER LEFT GRID SQUARE: ";LX;" ";LY
1050 PRINT "SIZE OF MAP: ";L;" BY ";W
1060 PRINT "BASE ELEVATION: ";HL(0,0,0)
1070 PRINT
1080 FOR I = 1 TO L
1090 FOR J = 1 TO W
1100 PRINT I,J,HL(I,J,0)
1110 IF HL(I,J,0) = 0 THEN 1160
1120 FOR K = 1 TO HL(I,J,0)
1130 PRINT HL(I,J,K);" ";
1140 NEXT K
1150 PRINT
1160 NEXT J
1170 PRINT : NEXT I
1180 PR# 0
1190 PRINT : PRINT
1200 INPUT "HIT RETURN TO CONTINUE":X$
1210 GOTO 30

```





## E. HILL MAKER PROGRAM

```

10 REM - HILL DATA FILE MAKER/READER
20 DIM H(200,8),K(8)
30 K(1) = 5:K(2) = 9:K(3) = 14:K(4) = 18
40 K(5) = 22:K(6) = 24:K(7) = 29:K(8) = 33
50 REM HILL DATA FILE MAKER
60 HOME : UTAB 2
70 PRINT "MENU:"
80 PRINT "1 HILL MAKER"
90 PRINT "2 HILL READER"
100 PRINT "0 QUIT"
110 PRINT : INPUT "WHICH? ";X
120 IF X = 0 THEN END
130 ON X GOTO 150,820
140 REM HILL DATA FILE MAKER
150 HOME : UTAB 2
160 PRINT TAB(11); "*** HILL MAKER ***"
170 PRINT : PRINT
180 INPUT "NEW OR OLD FILE? (N/O) ";A$
190 IF A$ = "N" THEN 230
200 GOSUB 560
210 INPUT "WHICH HILL DO YOU WANT TO START WITH? ";II
220 GOTO 260
230 HOME : UTAB 4
240 II = 1
250 INPUT "NUMBER OF HILLS? ";N
260 FOR I = II TO N
270 PRINT "ENTER THE DATA FOR HILL ";I
280 INPUT "XCOORD IS ";H(I,1)
290 INPUT "YCOORD IS ";H(I,2)
300 INPUT "PEAK ELEVATION IS ";H(I,3)
310 INPUT "ORIENTATION ANGLE IS ";H(I,4)
320 INPUT "ECCENTRICITY IS ";H(I,5)
330 INPUT "SPREAD IS ";H(I,6)
340 INPUT "MAX HEIGHT IS ";H(I,7)
350 INPUT "CUT HEIGHT IS ";H(I,8)
360 PRINT : PRINT : INPUT "SAVE? (Y/N) ";Z$
370 IF Z$ = "Y" THEN 390
380 NEXT I
390 HOME : UTAB 4
400 O$ = CHR$(4)
410 INPUT "NAME OF FILE? ";N$
420 PRINT O$;"OPEN ";N$;".HILLS, L34"
430 PRINT O$;"WRITE ";N$;".HILLS, R0"
440 PRINT N
450 FOR I = 1 TO N
460 PRINT O$;"WRITE ";N$;".HILLS, R";I

```



```

470 FOR J = 1 TO 8
480 PRINT H(I,J)
490 NEXT J
500 NEXT I
510 PRINT O$;"CLOSE ";N$;".HILLS"
520 PRINT : PRINT : PRINT "... DONE"
525 PRINT : PRINT
530 INPUT "DO YOU WANT TO CONTINUE INPUTTING DATA? (Y/N) ";A$
540 IF A$ = "Y" THEN 210
550 GOTO 60
560 HOME
570 O$ = CHR$(4)
580 INPUT "NAME OF FILE? ";N$
590 PRINT O$;"OPEN ";N$;".HILLS. L34"
600 PRINT O$;"READ ";N$;".HILLS, R0"
610 INPUT N
620 FOR I = 1 TO N
630 PRINT O$;"READ ";N$;".HILLS, R";I
640 FOR J = 1 TO 8
650 INPUT H(I,J)
660 NEXT J
670 NEXT I
680 PRINT O$;"CLOSE ";N$;".HILLS"
690 HOME
700 PRINT "NUMBER OF HILLS: ";N: PRINT
710 M = 1
720 FOR I = 1 TO N
730 IF M = 11 THEN PRINT :M = 1
740 PRINT I;
750 FOR J = 1 TO 8
760 PRINT TAB( K(J));H(I,J);
770 NEXT J
780 PRINT
790 M = M + 1
800 NEXT I
810 RETURN

```



```

820 REM HILL DATA FILE READER
830 PR = 0
840 HOME : UTAB 2
850 PRINT TAB(10); "HILL READER ***"
860 PRINT : PRINT
870 O$ = CHR$(4)
880 INPUT "NAME OF MAP? "; N$
890 INPUT "PRINTER ON? (Y/N) "; Z$
900 IF Z$ = "Y" THEN PR = 1
910 PRINT O$; "OPEN "; N$; ".HILLS, L34"
920 PRINT O$; "READ "; N$; ".HILLS, R0"
930 INPUT N
940 FOR I = 1 TO N
950 PRINT O$; "READ "; N$; ".HILLS, R"; I
960 FOR J = 1 TO 8
970 INPUT H(I,J)
980 NEXT J
990 NEXT I
1000 PRINT O$; "CLOSE "; N$; ".HILLS"
1010 HOME
1020 IF PR = 1 THEN PR# 1
1030 PRINT : PRINT N$; " HILL DATA": PRINT
1040 PRINT "NUMBER OF HILLS: "; N
1050 PRINT
1060 M = 1
1070 FOR I = 1 TO N
1080 IF M = 11 THEN PRINT : M = 1
1090 PRINT I;
1100 FOR J = 1 TO 8
1110 KK = K(J) + 3 * J
1120 IF PR = 1 THEN POKE 36, KK: PRINT H(I,J); GOTO 1140
1130 PRINT TAB( K(J)); H(I,J);
1140 NEXT J
1150 PRINT
1160 M = M + 1
1170 NEXT I
1180 PR# 0
1190 INPUT "HIT RETURN TO CONTINUE"; X$
1200 GOTO 60

```



# F. WOODS MAKER PROGRAM

```

10 REM WOODS CATALOG MAKER/READER
20 DIM FL(10,10,9)
30 HOME : UTAB 3
40 PRINT "MENU:"
50 PRINT "1 WOODS MAKER"
60 PRINT "2 WOODS READER"
70 PRINT "0 QUIT"
80 PRINT : INPUT "WHICH? ";X
90 IF X = 0 THEN END
100 ON X GOTO 120,770
110 REM WOODS CATALOG MAKER
120 HOME : UTAB 2
130 PRINT TAB( 11); "*** WOODS MAKER ***"
140 PRINT : PRINT
150 INPUT "NEW OR OLD MAP? (N/O) ";Z$
160 IF Z$ = "N" THEN II = 1:JJ = 1: GOTO 220
170 INPUT "NAME OF MAP? ";M$
180 O$ = CHR$(4)
190 GOSUB 600
200 INPUT "ENTER STARTING GRID SQUARE (I,J) ";II,JJ
210 GOTO 240
220 INPUT "SIZE OF MAP (1000 M SQUARES)? ";L,W
230 INPUT "ENTER LOWER LEFT GRID SQUARE (EG. 50,93) ";LX,LY
240 FOR I = II TO L
250 FOR J = JJ TO W
260 PRINT : PRINT
270 PRINT "FOR GRID SQUARE ";I;",";J
280 INPUT "NUMBER OF FORESTS? ";FL(I,J,0):KK = FL(I,J,0)
290 IF KK = 0 THEN 370
300 PRINT "ENTER THE ";KK;" FORESTS FOR GRID SQUARE ";I;",";J
310 FOR K = 1 TO KK
320 PRINT "FOREST ";K;" IS "; INPUT FL(I,J,K)
330 NEXT K
340 JJ = 1
350 PRINT : INPUT "SAVE? (Y/N)";A$
360 IF A$ = "Y" THEN 390
370 NEXT J
380 NEXT I

```





```

380 HOME : VTAB 4
400 INPUT "NAME OF MAP FILE? ";M$
410 O$ = CHR$(4)
420 PRINT O$;"OPEN ";M$;".WOODS"
430 PRINT O$;"WRITE ";M$;".WOODS"
440 PRINT L: PRINT W
450 PRINT LX: PRINT LY
460 FOR I = 1 TO L
470 FOR J = 1 TO W
480 PRINT FL(I,J,0)
490 IF FL(I,J,0) = 0 THEN 530
500 FOR K = 1 TO FL(I,J,0)
510 PRINT FL(I,J,K)
520 NEXT K
530 NEXT J
540 NEXT I
550 PRINT O$;"CLOSE ";M$;".WOODS"
560 PRINT : PRINT : PRINT : PRINT "... DONE": PRINT : PRINT
570 INPUT "DO YOU WANT TO CONTINUE INPUTTING DATA? (Y/N) ";Z$
580 IF Z$ = "Y" THEN 200
590 GOTO 30
600 O$ = CHR$(4)
610 PRINT O$;"OPEN ";M$;".WOODS"
620 PRINT O$;"READ ";M$;".WOODS"
630 INPUT L: INPUT W
640 INPUT LX: INPUT LY
650 FOR I = 1 TO L
660 FOR J = 1 TO W
670 INPUT FL(I,J,0)
680 IF FL(I,J,0) = 0 THEN 720
690 FOR K = 1 TO FL(I,J,0)
700 INPUT FL(I,J,K)
710 NEXT K
720 NEXT J
730 NEXT I
740 PRINT O$;"CLOSE ";M$;".WOODS"
750 RETURN

```



```

760 REM WOODS CATALOG FILE READER
770 HOME : UTAB 2
780 PRINT TAB( 11);"*** WOODS READER ***"
790 PRINT : PRINT
800 INPUT "NAME OF MAP FILE? ";M$
810 INPUT "PRINTER ON? (Y/N) ";A$
820 O$ = CHR$(4)
830 PRINT O$;"OPEN ";M$;".WOODS"
840 PRINT O$;"READ ";M$;".WOODS"
850 INPUT L: INPUT W
860 INPUT LX: INPUT LY
870 FOR I = 1 TO L
880 FOR J = 1 TO W
890 INPUT FL(I,J,0)
900 IF FL(I,J,0) = 0 THEN 940
910 FOR K = 1 TO FL(I,J,0)
920 INPUT FL(I,J,K)
930 NEXT K
940 NEXT J
950 NEXT I
960 PRINT O$;"CLOSE ";M$;".WOODS"
970 HOME
980 IF A$ = "Y" THEN PR# 1
990 PRINT "NAME OF MAP: ";M$
1000 PRINT "LOWER LEFT GRID SQUARE: ";LX;" ";LY
1010 PRINT "SIZE OF MAP: ";L;" BY ";W
1020 PRINT
1030 FOR I = 1 TO L
1040 FOR J = 1 TO W
1050 PRINT I,J,FL(I,J,0)
1060 IF FL(I,J,0) = 0 THEN 1110
1070 FOR K = 1 TO FL(I,J,0)
1080 PRINT FL(I,J,K);" ";
1090 NEXT K
1100 PRINT
1110 NEXT J
1120 PRINT : NEXT I
1130 PR# 0
1140 PRINT : PRINT
1150 INPUT "HIT RETURN TO CONTINUE":X$
1160 GOTO 30

```



## G. FOREST MAKER PROGRAM

```

10 REM FOREST MAKER/READER
20 DIM F(120,6),K(6)
30 K(1) = 5:K(2) = 12:K(3) = 20:K(4) = 25
40 K(5) = 30:K(6) = 35
50 HOME : UTAB 2
60 PRINT "MENU: "
70 PRINT "1 FOREST MAKER"
80 PRINT "2 FOREST READER"
90 PRINT "0 QUIT"
100 PRINT : INPUT "WHICH? ";X
110 IF X = 0 THEN END
120 ON X GOTO 140,800
130 REM FOREST DATA FILE MAKER
140 HOME : UTAB 2
150 PRINT TAB(10);"*** FOREST MAKER ***"
160 PRINT : PRINT
170 INPUT "NEW OR OLD FILE? (N/O) ";A$
180 IF A$ = "N" THEN 220
190 GOSUB 530
200 INPUT "WHICH FOREST DO YOU WANT TO START WITH? ";I
210 GOTO 250
220 HOME : UTAB 4
230 II = 1
240 INPUT "NUMBER OF FORESTS? ";N
250 FOR I = II TO N
260 PRINT "ENTER THE DATA FOR FOREST ";I
270 INPUT "XCOORD IS ";F(I,1)
280 INPUT "YCOORD IS ";F(I,2)
290 INPUT "HEIGHT OF TREES IS ";F(I,3)
300 INPUT "ORIENTATION ANGLE IS ";F(I,4)
310 INPUT "SEMI-MAJOR AXIS LENGTH IS ";F(I,5)
320 INPUT "SEMI-MINOR AXIS LENGTH IS ";F(I,6)
330 PRINT : PRINT : INPUT "SAVE? (Y/N) ";Z$
340 IF Z$ = "Y" THEN 360
350 NEXT I
360 HOME : UTAB 4
370 O$ = CHR$(4)

```



```

380 INPUT "NAME OF FILE? ";N$
390 PRINT O$;"OPEN ";N$;".FORESTS, L38"
400 PRINT O$;" WRITE ";N$;".FORESTS, R0"
410 PRINT N
420 FOR I = 1 TO N
430 PRINT O$;"WRITE ";N$;".FORESTS, R":I
440 FOR J = 1 TO 6
450 PRINT F(I,J)
460 NEXT J
470 NEXT I
480 PRINT O$;"CLOSE ";N$;".FORESTS"
490 PRINT : PRINT : PRINT "... DONE"
495 PRINT : PRINT
500 INPUT "DO YOU WANT TO CONTINUE INPUTTING DATA? (Y/N) ";A$
510 IF A$ = "Y" THEN 200
520 GOTO 50
530 HOME
540 O$ = CHR$(4)
550 INPUT "NAME OF FILE? ";N$
560 PRINT O$;"OPEN ";N$;".FORESTS, L38"
570 PRINT O$;"READ ";N$;".FORESTS, R0"
580 INPUT N
590 FOR I = 1 TO N
600 PRINT O$;"READ ";N$;".FORESTS, R":I
610 FOR J = 1 TO 6
620 INPUT F(I,J)
630 NEXT J
640 NEXT I
650 PRINT O$;"CLOSE ";N$;".FORESTS"
660 HOME
670 PRINT N$;" FORESTS LIST": PRINT
680 PRINT "NUMBER OF FORESTS: ";N: PRINT
690 M = 1
700 FOR I = 1 TO N
710 IF M = 11 THEN PRINT :M = 1
720 PRINT I;
730 FOR J = 1 TO 6
740 PRINT TAB( K(J));F(I,J);
750 NEXT J
760 PRINT
770 M = M + 1
780 NEXT I
790 RETURN

```





```

800 REM   FOREST DATA FILE READER
810 HOME : UTAB 2
820 PR = 0
830 PRINT TAB( 10); "*** FOREST READER ***"
840 PRINT : PRINT
850 OS = CHR$( 4)
860 INPUT "NAME OF MAP? ";N$
870 INPUT "PRINTER ON? (Y/N) ";Z$
880 IF Z$ = "Y" THEN PR = 1
890 PRINT OS;"OPEN ";N$;".FORESTS. L38"
900 PRINT OS;"READ ";N$;".FORESTS. R0"
910 INPUT N
920 FOR I = 1 TO N
930 PRINT OS;"READ ";N$;".FORESTS. R";I
940 FOR J = 1 TO 6
950 INPUT F(I,J)
960 NEXT J
970 NEXT I
980 PRINT OS;"CLOSE ";N$;".FORESTS"
990 HOME
1000 IF PR = 1 THEN PR# 1
1010 PRINT : PRINT N$;" FOREST DATA": PRINT
1020 PRINT "NUMBER OF FORESTS ";N
1030 PRINT
1040 M = 1
1050 FOR I = 1 TO N
1060 IF M = 11 THEN PRINT :M = 1
1070 PRINT I;
1080 FOR J = 1 TO 6
1090 KK = K(J) + 3 * J
1100 IF PR = 1 THEN POKE 36,KK: PRINT F(I,J);: GOTO 1120
1110 PRINT TAB( K(J));F(I,J);
1120 NEXT J
1130 PRINT
1140 M = M + 1
1150 NEXT I
1160 PR# 0
1170 INPUT "HIT RETURN TO CONTINUE";X$
1180 GOTO 50

```



# H. TERRAIN MODEL PROGRAM

```

10 REM UPDATED 02 FEB 82
20 REM DAMSTAC TERRAIN MODEL
30 DIM XB(5),YB(5),XB(5),YB(5),RX(5,10),RY(5,10),RX(5,10)
35 DIM ZB(5),ZB(5),HL(10,10,12)
40 DIM BP(5),BP(5),SB(5),SR(5),RY(5,10)
50 DIM BF(5),RF(5),BT(5,5),RT(5,5),OB(5),OR(5)
60 DIM BR(5),RR(5)
70 DIM B1(5),R1(5)
80 T = 0:DT = 30:MT = 1500
90 D$ = CHR$(4)
100 P = 0.99:Q = 0.93
110 PI = 3.141592654:PR = 0
120 A = 2.4:B = 0.03
130 BE = 0.3:RE = 0.3
140 BM = .5:RM = .5
150 KK = 0
160 NK = MT / DT
165 ZZ = 1
170 DIM B0(NK),R0(NK)
171 HOME
172 INPUT "NAME OF MAP FILE? ";M$
173 PRINT D$;"OPEN ";M$;".MAP"
174 PRINT D$;"READ ";M$;".MAP"
175 INPUT L: INPUT W
176 INPUT LX: INPUT LY
177 INPUT HL(0,0,0)
178 FOR I = 1 TO L
179 FOR J = 1 TO W
180 INPUT HL(I,J,0)
181 IF HL(I,J,0) = 0 THEN 184
182 FOR K = 1 TO HL(I,J,0)
183 INPUT HL(I,J,K)
184 NEXT : NEXT : NEXT
185 PRINT D$;"CLOSE ";M$;".MAP"
186 LX = LX - 1:LY = LY - 1
187 PRINT D$;"OPEN ";M$;".HILLS, L34"
188 PRINT D$;"READ ";M$;".HILLS. RM"
189 INPUT NH: DIM H(NH,8)
190 FOR I = 1 TO NH
191 PRINT D$;"READ ";M$;".HILLS, R";I
192 FOR J = 1 TO 8
193 INPUT H(I,J)
194 NEXT : NEXT
195 PRINT D$;"CLOSE ";M$;".HILLS"

```



```

198 HOME
199 INPUT "NAME OF FILE FOR BLUE DATA? ";N$
200 PRINT O$;"OPEN ";N$;".BLUE"
210 PRINT O$;"READ ";N$;".BLUE"
220 INPUT M
230 FOR I = 1 TO M
240 INPUT B1
250 FOR J = 1 TO B1
260 INPUT BX(I,J): INPUT BY(I,J)
270 NEXT : NEXT
280 PRINT O$;"CLOSE ";N$;".BLUE"
290 FOR I = 1 TO M:XB(I) = BX(I,1):YB(I) = BY(I,1):BP(I) = 1
300 PRINT B1: FOR JJ = 1 TO B1: PRINT BX(I,JJ),BY(I,JJ): NEXT JJ
310 PRINT "SIZE OF BLUE UNIT ";I:: INPUT SB(I)
320 B1(I) = SB(I)
330 B0(0) = B0(0) + SB(I)
340 BR(I) = 0
341 X = XB(I):Y = YB(I)
342 X4 = INT (XB(I) / 1000) - LX:Y4 = INT (YB(I) / 1000) - LY
343 GOSUB 1960
344 ZB(I) = Z
345 PRINT "ELEVATION OF BLUE ";I:" IS ";Z
346 FOR I1 = 1 TO HL(X4,Y4,0):H2 = HL(X4,Y4,I1):H(H2,0) = 0: NEXT
350 NEXT
360 PRINT
370 INPUT "NAME OF FILE FOR RED DATA? ";N$
380 PRINT O$;"OPEN ";N$;".RED"
390 PRINT O$;"READ ";N$;".RED"
400 INPUT N
410 FOR I = 1 TO N
420 INPUT R1
430 FOR J = 1 TO R1
440 INPUT RX(I,J): INPUT RY(I,J)
450 NEXT : NEXT
460 PRINT O$;"CLOSE ";N$;".RED"
470 FOR I = 1 TO N:XR(I) = RX(I,1):YR(I) = RY(I,1):RP(I) = 1
480 PRINT "SIZE OF RED UNIT ";I:: INPUT SR(I)
490 R1(I) = SR(I)
500 R0(0) = R0(0) + SR(I)
510 RR(I) = 5
511 X = XR(I):Y = YR(I)
512 X4 = INT (XR(I) / 1000) - LX:Y4 = INT (YR(I) / 1000) - LY
513 GOSUB 1960
514 ZR(I) = Z
515 PRINT "ELEVATION OF RED ";I:" IS ";Z
516 FOR I1 = 1 TO HL(X4,Y4,0):H2 = HL(X4,Y4,I1):H(H2,0) = 0: NEXT
520 NEXT I

```



```

530 PRINT : INPUT "DO YOU WANT THE PRINTER ON? (Y/N) " : A$
535 IF A$ = "Y" THEN PR = 1
540 HOME : UTAB 3
550 IF PR = 1 THEN PR# 1
560 PRINT
570 PRINT "TIME": POKE 36,7: PRINT "BLUE": POKE 36,20: PRINT "RED"
580 PR# 0
590 IF ZZ = 1 THEN GOSUB 1760: GOTO 610
600 GOSUB 1490
610 REM MAIN PROGRAM
620 T = T + OT
630 IF T <= MT THEN 640
635 PRINT "END OF BATTLE DUE TO TIME": GOSUB 1540: END
640 GOSUB 790
650 GOSUB 1170
660 KK = KK + 1
670 B0(KK) = 0: R0(KK) = 0
680 FOR I = 1 TO M
690 B0(KK) = B0(KK) + SB(I)
700 NEXT I
710 FOR J = 1 TO N
720 R0(KK) = R0(KK) + SR(J)
730 NEXT J
740 IF ZZ = 1 THEN GOSUB 1760: GOTO 760
750 GOSUB 1490
760 IF B0(KK) > BE * B0(0) THEN 770
765 PRINT : PRINT "END OF BATTLE DUE TO ATTRITION OF BLUE"
766 GOSUB 1540: END
770 IF R0(KK) > RE * R0(0) THEN 780
775 PRINT : PRINT "END OF BATTLE DUE TO ATTRITION OF RED"
776 GOSUB 1540: END
780 GOTO 620
790 REM MOVEMENT SUBROUTINE
800 FOR I = 1 TO N
810 J = RP(I)
820 OY = RY(I,J + 1) - YR(I)
830 OX = RX(I,J + 1) - XR(I)
840 IF OX = 0 AND OY > 0 THEN AN = PI / 2: GOTO 880
850 IF OX = 0 AND OY < 0 THEN AN = 3 * PI / 2: GOTO 880
860 AN = ATN(OY / OX)
870 IF OX < 0 THEN AN = PI + AN
880 O1 = OT * RR(I) * COS(AN)
890 O2 = OT * RR(I) * SIN(AN)
900 OH = SQR(O1 ^ 2 + O2 ^ 2)
910 OI = SQR(OX ^ 2 + OY ^ 2)
920 IF OI >= OH THEN 950
930 O1 = OX: O2 = OY
940 RP(I) = J + 1

```





```

950 YR(I) = INT (YR(I) + 02)
960 XR(I) = INT (XR(I) + 01)
961 X = XR(I):Y = YR(I)
962 X4 = INT (XR(I) / 1000) - LX:Y4 = INT (YR(I) / 1000) - LY
963 GOSUB 1960
964 ZR(I) = Z
965 PRINT "ELEVATION OF RED ";I;" IS ";Z
966 FOR I1 = 1 TO HL(X4,Y4,0):H2 = HL(X4,Y4,I1):H(CH2,0) = 0: NEXT
970 NEXT
980 FOR I = 1 TO M
990 J = BP(I)
1000 OY = BY(I,J + 1) - YB(I)
1010 OX = BX(I,J + 1) - XB(I)
1020 IF OX = 0 AND OY > 0 THEN AN = PI / 2: GOTO 1060
1030 IF OX = 0 AND OY < 0 THEN AN = 3 * PI / 2: GOTO 1060
1040 AN = ATN (OY / OX)
1050 IF OX < 0 THEN AN = PI + AN
1060 O1 = OT * BR(I) * COS (AN)
1070 O2 = OT * BR(I) * SIN (AN)
1080 OH = SQR (O1 ^ 2 + O2 ^ 2)
1090 OI = SQR (OX ^ 2 + OY ^ 2)
1100 IF OI > = OH THEN 1130
1110 O1 = OX:O2 = OY
1120 BP(I) = J + 1
1130 YB(I) = INT (YB(I) + 02)
1140 XB(I) = INT (XB(I) + 01)
1150 NEXT
1160 RETURN
1170 REM ATTRITION SUBROUTINE
1180 FOR I = 1 TO M:BF(I) = 0:OB(I) = 0: NEXT
1190 FOR J = 1 TO N:RF(J) = 0:OR(J) = 0: NEXT
1200 FOR I = 1 TO M
1210 FOR J = 1 TO N
1220 BT(I,J) = 0:RT(J,I) = 0
1230 RG = SQR ((XB(I) - XR(J)) ^ 2 + (YB(I) - YR(J)) ^ 2)
1240 IF RG > 2700 THEN 1310
1250 RR(I) = Z
1251 REM CHECK LINE OF SIGHT
1252 X1 = INT (XB(I) / 1000) - LX:Y1 = INT (YB(I) / 1000) - LY
1253 X2 = INT (XR(J) / 1000) - LX:Y2 = INT (YR(J) / 1000) - LY
1254 X3 = X2 - X1:Y3 = Y2 - Y1
1255 FOR I1 = 0 TO ABS (X3)
1256 X4 = X1 + I1 * SGN (X3)
1257 FOR J1 = 0 TO ABS (Y3)
1258 Y4 = Y1 + J1 * SGN (Y3)
1261 PRINT "CHECKING GRID SQUARE ";X4;" ";Y4:" FOR BLUE ";I;" RED ";J

```



```

1262 GOSUB 1960
1263 NEXT : NEXT
1264 FOR I1 = 1 TO NH:HK(I1,0) = 0: NEXT
1265 REM LOS IS OK
1270 BF(I) = BF(I) + 1
1280 RF(J) = RF(J) + 1
1290 BT(I,J) = A * (1 - (P) ^ SB(I)) * SR(J)
1300 RT(J,I) = B * (1 - (Q) ^ SR(J)) * SB(I)
1310 NEXT : NEXT
1320 FOR I = 1 TO M
1330 FOR J = 1 TO N
1340 IF RF(J) = 0 OR BF(I) = 0 THEN 1370
1350 OB(I) = OB(I) + BT(I,J) / RF(J)
1360 OR(J) = OR(J) + RT(J,I) / BF(I)
1370 NEXT : NEXT
1380 FOR I = 1 TO M
1390 SB(I) = SB(I) - OB(I)
1400 IF SB(I) < 0 THEN SB(I) = 0
1410 IF SB(I) < = BM * B1(I) THEN BR(I) = 8
1420 NEXT
1430 FOR J = 1 TO N
1440 SR(J) = SR(J) - OR(J)
1450 IF SR(J) < 0 THEN SR(J) = 0
1460 IF SR(J) < = RM * R1(I) THEN RR(I) = - 8
1470 NEXT
1480 RETURN
1490 REM PRINTOUT/SUMMARY
1500 IF PR = 1 THEN PR# 1
1510 PRINT T: POKE 36,7: PRINT B0(KK): POKE 36,20: PRINT R0(KK)
1520 PR# 0
1530 RETURN
1540 REM SAVE RESULTS IN A FILE
1550 PRINT : INPUT "DO YOU WANT A FILE OF THIS RUN'S DATA? (Y/N) ":A$
1560 IF A$ = "N" THEN 1750
1570 O$ = CHR$(4)
1580 INPUT "NAME OF FILE FOR FORCE LEVEL DATA? ":F$
1590 PRINT O$;"OPEN ";F$;".COEFS"
1600 PRINT O$;"WRITE ";F$;".COEFS"
1610 PRINT A: PRINT B: PRINT P: PRINT Q
1620 PRINT O$;"CLOSE ";F$;".COEFS"
1630 PRINT O$;"OPEN ";F$;".RESULTS"
1640 PRINT O$;"WRITE ";F$;".RESULTS"
1650 PRINT NK + 1: PRINT NK + 1
1660 FOR I = 0 TO NK
1670 T = I * 3
1680 PRINT T: PRINT SB(I)
1690 NEXT I

```



```

1700 FOR I = 0 TO NK
1710 T = I * 3
1720 PRINT T: PRINT R0(I)
1730 NEXT I
1740 PRINT 0$;"CLOSE ";F$;".RESULTS"
1750 RETURN
1760 REM PRINTOUT/SUMMARY
1770 HOME : UTAB 3
1780 IF PR = 1 THEN PR# 1
1790 PRINT "TIME IS ";T
1800 PRINT : PRINT
1810 PRINT "BLUE FORCES"
1820 PRINT "UNIT"; TAB( 7);"XCOORD"; TAB( 15);"YCOORD"; TAB( 23);"SIZE"
1830 FOR I = 1 TO M
1840 PRINT " ";I; TAB( 7);XB(I); TAB( 15);YB(I); TAB( 24);SB(I)
1850 NEXT
1860 PRINT : PRINT "RED FORCES"
1870 PRINT "UNIT"; TAB( 7);"XCOORD"; TAB( 15);"YCOORD"; TAB( 23);"SIZE"
1880 FOR I = 1 TO N
1890 PRINT " ";I; TAB( 7);XR(I); TAB( 15);YR(I); TAB( 24);SR(I)
1900 NEXT
1910 PRINT : PRINT
1920 PR# 0
1930 INPUT "HIT RETURN TO CONTINUE":Z$
1940 RETURN
1950 REM ELEVATION COMPUTATION
1960 CR = - 99999999
1970 Z = HL(0,0,0)
1980 FOR H1 = 1 TO HL(X4,Y4,0)
1990 H2 = HL(X4,Y4,H1)
2000 IF H(H2,0) = 1 THEN 2150
2010 XS = X - H(H2,1) * 100:YS = Y - H(H2,2) * 100
2020 A1 = LOG (H(H2,7) / (H(H2,7) - 50))
2030 B1 = A1 * (H(H2,5)) ^ 2
2040 C1 = H(H2,4) * PI / 180
2050 C2 = H(H2,6) ^ 2
2060 P1 = - (A1 * ( COS (C1)) ^ 2 + B1 * ( SIN (C1)) ^ 2) / C2
2070 P2 = - (A1 * ( SIN (C1)) ^ 2 + B1 * ( COS (C1)) ^ 2) / C2
2080 P3 = (2 * COS (C1) * SIN (C1) * (B1 - A1)) / C2
2090 IF H(H2,7) > H(H2,8) THEN CR = LOG ((H(H2,7) - H(H2,8)) / H(H2,7))
2100 Q1 = P1 * XS ^ 2 + P2 * YS ^ 2 + P3 * XS * YS
2110 H(H2,0) = 1
2120 IF Q1 < CR THEN 2150
2130 FI = H(H2,3) + H(H2,7) * ( EXP (Q1) - 1)
2140 IF FI > Z THEN Z = FI
2150 NEXT
2160 RETURN

```





# I. POSTPROCESSOR PROGRAM

```

//PRO9      JOB (3102,1087),HOCK SMC1013.
//EXEC      SIM25CLG
//SIM.SYSIN DD *
PREAMBLE
THE SYSTEM OWNS A SHOTLIST
THE SYSTEM OWNS A CASLIST
PERMANENT ENTITIES
DEFINE VEHCOUNT, MAXBLUE, MAXREC AS INTEGER VARIABLES
DEFINE BLUE.TIME, RED.TIME, TOTAL.TIME AS REAL VARIABLES
DEFINE TOTAL.CAS AS A REAL VARIABLE
TEMPORARY ENTITIES
GENERATE LIST ROUTINES
EVERY SHOT HAS A TTT, A TIME, A RANGE, A FNAME, A FSWTYPE,
A TNAME, A TSWTYPE, A STATUS,
AND BELONGS TO A SHOTLIST
EVERY CAS HAS A NUMCAS, A TIMECAS, A TGT.CAS, A T.BTWN.CAS,
A TYPE.CAS, A STATUS.CAS, A T.CASLIST
AND BELONGS TO A CASLIST
AND SET RANKED BY LOW TIMECAS
DEFINE SHOTLIST AS A RANGE, FNAME AS INTEGER VARIABLES
DEFINE TTT, RANGE, TSWTYPE, TNAME AS ALPHA VARIABLES
DEFINE FSWTYPE, TTYPE, STATUS AS INTEGER VARIABLES
DEFINE TIME, BTWN.CAS AS INTEGER VARIABLES
DEFINE NSHOT AS AN INTEGER VARIABLE
DEFINE CASLIST AS A SET RANKED BY LOW TIMECAS
DEFINE T.CAS, NUMBL.CAS, NUMRD.CAS AS INTEGER VARIABLES
DEFINE NUMCAS, TIMECAS, TGT.CAS AS INTEGER VARIABLES
DEFINE TYPE.CAS, STATUS.CAS AS ALPHA VARIABLES
DEFINE VAR1, VAR2, VAR3, VAR4, VAR5, VAR6 AS REAL VARIABLES
DEFINE MINP, MINC, PHAT, QHAT, AHAT, P AS REAL VARIABLES
DEFINE LP, LK, ACR, CB AS INTEGER VARIABLES
DEFINE MK1, NK1 AS INTEGER VARIABLES
DEFINE RUNNO, TMCAS, CURTIME AS INTEGER VARIABLES
DEFINE TBLUE, TRREC AS INTEGER VARIABLES
DEFINE TMBLCA, TRMDCAS AS INTEGER VARIABLES
DEFINE NSHOT AS THE NUMBER OF TNAME
ACCUMULATE NSHOT AS THE NUMBER OF TNAME
TALLY J.BL AS THE NUMBER, BLMU AS THE MEAN, BLSIG AS THE STD.DEV,
AND BLHST(0 TO 200 BY 10) AS THE HISTOGRAM OF BLUE.TIME
TALLY J.RD AS THE NUMBER, RDMU AS THE MEAN, RDSIG AS THE STD.DEV,
AND RDHST(0 TO 200 BY 10) AS THE HISTOGRAM OF RED.TIME
TALLY JTOT AS THE NUMBER, TOTMU AS THE MEAN, TOTSIG AS THE STD.DEV,
AND TOTHST(0 TO 200 BY 10) AS THE HISTOGRAM OF TOTAL.TIME
TALLY JCAS AS THE NUMBER, CASMU AS THE MEAN, CASIG AS THE STD.DEV,
AND CASHST (0 TO 1600 BY 100) AS THE HISTOGRAM OF TOTAL.CAS
END
MAIN
DEFINE I AS AN INTEGER VARIABLE
DEFINE II AS AN INTEGER VARIABLE

```





```

READ RUNNO, VEHCOUNT, MAXBLUE, MAXRED
PRINT 1 LINE WITH RUNNO, MAXRED
+++++++ RUN NUMBER ***** ++++++
SKIP TWO LINES
PRINT 1 LINE WITH MAXBLUE, MAXRED, INITIAL RED STRENGTH = *****
SKIP TWO LINES
USE UNIT 12 FOR INPUT
LET I = 0
'NEW, CREATE A SHOT
'READ,
IF DATA IS ENDED, GO TO 'PROCESS, ELSE START NEW RECORD
IF MODE IS NOT INTEGER, SKIP 1 RECORD GO TO 'READ, ELSE
SKIP 4 FIELDS, READ FSWTYPE(SHOT)
IF FSWTYPE(SHOT) EQUALS "EXPD" GO TO 'READ2, ELSE
LET RCOLUMN.V=1
READ TTT(SHOT), TIME(SHOT), RANGE(SHOT), FNAME(SHOT),
FSWTYPE(SHOT)
SKIP 12 FIELDS, READ TNAME(SHOT), TSWTYPE(SHOT)
IF FSWTYPE(SHOT) IS EQUAL TO "2-4" OR FSWTYPE(SHOT) = "2-8"
DESTROY THIS SHOT, LET RCOLUMN.V=132 GO TO 'NEW, ALWAYS
IF FSWTYPE(SHOT) IS EQUAL TO "3-6" OR FSWTYPE(SHOT) = "4-1"
DESTROY THIS SHOT, LET RCOLUMN.V=132 GO TO 'NEW, ALWAYS
FILE SHOT IN SHOTLIST
LET RCOLUMN.V=132
GO TO 'NEW,
'READ2,
LET RCOLUMN.V=1
SKIP 2 FIELDS, READ TIME(SHOT), SKIP 1 FIELD, READ TNAME(SHOT),
TSWTYPE(SHOT)
SKIP 5 FIELDS, READ STATUS(SHOT)
FILE SHOT IN SHOTLIST
LET RCOLUMN.V=132
GO TO 'NEW,
'PROCESS,
.. LIST ATTRIBUTES OF EACH SHOT IN SHOTLIST
.. PRINT 1 LINE WITH NSHOT, THUS
.. THE NUMBER OF SHOTS IN THE LIST = *****
.. THIS PORTION OF PROGRAM FINDS THE CASUALTIES
'NEWCAS,
FOR EACH SHOT IN SHOTLIST, DO
IF STATUS(SHOT) IS NOT EQUAL TO "DEAD" GO TO 'LOOP, ALWAYS
ADD 1 TO I.CAS
IF TNAME(SHOT) IS GREATER THAN 41, ADD 1 TO NUMBL.CAS, ELSE
CREATE A CAS

```



```

..
..
LET NUMCAS(CAS) = T.CAS (SHOT)
LET TIMECAS(CAS) = TIME TOTAL.CAS
LET TOTAL.CAS = TIME TOTAL.CAS + TIME TOTAL.CAS
PRINT 1 LINE WITH = ***.CAS(CAS) = 0 ELSE
IF T.CAS = 1 LET CAS = T.BTN.CAS(CAS) - TMCAS ALWAYS
LET T.BTN.CAS = T.BTN.CAS(CAS) ALWAYS
LET TOTAL.CAS = 1 RESET THE TOTALS OF TOTAL.TIME ALWAYS
IF T.CAS = 1 WITH TOTAL.CAS
PRINT 1 LINE WITH ***.CAS(CAS)
TOTAL.CAS = TIMECAS(CAS)
LET TGT.CAS(CAS) = TNAME(SHOT)
LET TYPE(CAS) = TNAME(SHOT) IS GREATER THAN 41 GO TO 'RED' ELSE
IF TYPE(CAS) = 'BLUE'
LET STATUS(CAS) = TIMECAS(CAS) - TMBLCAS
LET TMBLCAS = TIMECAS(CAS)
PRINT 1 LINE WITH ***.CAS(CAS)
BLUE.TIME = ***.CAS(CAS)
IF NUMBL.CAS = 1 RESET THE TOTALS OF BLUE.TIME ALWAYS
FILE CAS IN CASLIST
GO TO LOOP
LET STATUS(CAS) = 'RED'
LET RED.TIME = TIMECAS(CAS) - TMRDCAS
LET TMRDCAS = TIMECAS(CAS)
PRINT 1 LINE WITH RED.TIME
RED.TIME = ***.CAS(CAS)
IF NUMRD.CAS = 1 RESET THE TOTALS OF RED.TIME ALWAYS
FILE CAS IN CASLIST
LOOP
LET NUMBL.CAS = T.CAS - NUMRD.CAS
PRINT 1 LINE WITH T.CAS, NUMBL.CAS, NUMRD.CAS
T.CAS = ***.CAS, NUMBL.CAS, NUMRD.CAS = ****
LIST ATTRIBUTES OF EACH CAS IN CASLIST
PRINT 4 LINES
SHOT LIST DATA FOR CASUALTIES FOR THIS STAR SIMULATION
FOR EACH TARGET SYS-WPN TYPE TIME BETWEEN CASUALTIES
CAS IN CASLIST, PRINT 1 LINE WITH NUMCAS(CAS), TIMECAS(CAS),
TGT.CAS(CAS), TYPE(CAS), T.BTN.CAS(CAS)
***
SKIP 2 LINES
PRINT 2 LINES
NUMBL.CAS, BLMU, BLSIG, RDSIG, RDMU,
NUMRD.CAS, BLMU, RDSIG, RDMU,
NUMBER OF BLUE KILLED = ****
NUMBER OF RED KILLED = ****
BLSIG = ****
RDSIG = ****

```



```

PRINT 4 LINES THUS
HISTOGRAM OF BLUE AND RED CASUALTIES
(DATA BASED ON TIME BETWEEN BLUE CASUALTIES
AND TIME BETWEEN RED CASUALTIES)
PRINT 2 LINES THUS

INTERVAL=10 UNITS #BLUE CAS #RED CAS
FOR I = 1 TO 21, PRINT 1 LINE WITH I, BLHST(I), RDHST(I) THUS
***

SKIP 2 LINES
PRINT 1 LINE WITH I, CAS, TOTMU, TOTSIG THUS
TOTAL CASUALTIES = ***** TOTMU = ***** TOTSIG = *****
SKIP 2 LINES
PRINT 3 LINES THUS
HISTOGRAM OF TIME BETWEEN CASUALTIES(TOTAL)

INTERVAL=10 UNITS #CASUALTIES
FOR I = 1 TO 21, PRINT 1 LINE WITH I, TOTHST(I) THUS
***

SKIP 2 LINES
PRINT 3 LINES THUS
THE FOLLOWING DATA IS BASED ON CASUALTIES AS
THEY OCCUR ON THE TIME LINE (I.E. THE NUMBER
OF CASUALTIES THAT OCCUR IN THE FIRST 100 UNITS)

SKIP 2 LINES
PRINT 1 LINE WITH I, CAS, CASMU, CASIG THUS
TOTAL CASUALTIES = ***** CASMU = ***** CASIG = *****
PRINT 2 LINES THUS

HISTOGRAM OF TOTAL CASUALTIES AS A FUNCTION OF TIME PERIOD
PRINT 2 LINES THUS

INTERVAL=100 UNITS #CASUALTIES
FOR I = 1 TO 17, PRINT 1 LINE WITH I, CASHST(I) THUS
*****
LET MINP=1.0 LET MINQ=1.0 LET PHAT=1.0 LET QHAT=1.0
FOR P = .010 TO .59 BY .01, DO
LET NK1 = MAXRED LET MK1 = MAXBLUE
LET VAR1 = 0 LET VAR2 = 0 LET VAR3 = 0
LET VAR4 = 0 LET VAR5 = 0 LET VAR6 = 0
FOR EACH CAS IN CASLIST, DO
PRINT 1 LINE WITH STATUS, CAS(CAS), I, BTWN, CAS(CAS) THUS
***** TIME = *****
IF NUMCAS(CAS) = 1 CYCLE ALWAYS
IF STATUS.CAS(CAS) = "RED" LET CK=0
LET NK1=NK1-1 ALWAYS

```





```

IF STATUS.CAS(CAS) = "BLUE" LET CK=1
  LET MK1=MK1-1 ALWAYS
  PRINT 1 LINE WITH NK1,MK1,CK,P THUS
  NK1 = ***** CK = ** P = *.****
  LET VAR1=VAR1+((1-P**MK1)*NK1)*((1-BTWN.CAS(CAS)))
  LET VAR2=VAR2+((MK1-P**((MK1-1)*NK1)*((1-BTWN.CAS(CAS))))
  LET VAR3=VAR3+((CK**MK1)*P**((MK1-1)))/(1-P**MK1)
  LET VAR4=VAR4+((1-P**NK1)*NK1)*((1-BTWN.CAS(CAS)))
  LET VAR5=VAR5+((NK1-P**((NK1-1)*MK1)*((1-BTWN.CAS(CAS))))
  LET VAR6=VAR6+((1-CK)*NK1)*P**((NK1-1))/(1-P**NK1)
  LOOP
  PRINT 2 LINES WITH VAR1,VAR2,VAR3,VAR4,VAR5,VAR6 THUS
  VAR1=***** VAR2=***** VAR3=*****
  VAR4=***** VAR5=***** VAR6=*****
  LET LP=TBUE/VAR1-VAR3/VAR2
  LET LP=NUMBL.CAS/VAR1-VAR3/VAR2
  IF ABS.F(LP) < MINP LET MINP = ABS.F(LP) ALWAYS
  LET LC=NUMRC.CAS/VAR4-VAR6/VAR5
  IF ABS.F(LC) < MINQ LET MINQ = ABS.F(LC) ALWAYS
  LET QHAT = P LET BHAT=NUMRD.CAS/VAR4
  PRINT 1 LINE WITH NK1,MK1 THUS
  NK1=*****
  PRINT 1 LINE WITH PHAT,QHAT,AHAT,BHAT THUS
  PHAT=***** QHAT=***** AHAT=***** BHAT=*****
  PRINT 1 LINE WITH LP,LQ THUS
  LP = ***** LQ = *****
  LOOP
STOP END
//GO.SIMU06 DD DISP=SHR,VOL=SER=MVS004,UNIT=3350,DSN=S3102.TRANFILE
//GO.SIMU12 DD DISP=SHR,DSN=MSS.S3102.THEISIS(TABLE6)
//GC.SYSIN DD *
59 186 12 30

```





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